# Technical Report Documentation Page

**1. REPORT No.**
8-712

**2. GOVERNMENT ACCESSION No.**

**3. RECIPIENT'S CATALOG No.**

**4. TITLE AND SUBTITLE**
Bridge Deck Frosting-- Valley Environment

**5. REPORT DATE**
November 1971

**6. PERFORMING ORGANIZATION**

**7. AUTHOR(S)**
Stewart, C.F. and Sequeira, A.

**8. PERFORMING ORGANIZATION REPORT No.**
8-712

**9. PERFORMING ORGANIZATION NAME AND ADDRESS**
State of California
Business and Transportation Agency
Department of Public Works
Division of Highways
Bridge Department

**10. WORK UNIT No.**

**11. CONTRACT OR GRANT No.**

**12. SPONSORING AGENCY NAME AND ADDRESS**

**13. TYPE OF REPORT & PERIOD COVERED**

**14. SPONSORING AGENCY CODE**

**15. SUPPLEMENTARY NOTES**

**16. ABSTRACT**
Preferential frosting of bridge decks in California's moderate climate valley areas is a hazard to unsuspecting motorists. Salting to prevent this frosting causes premature deck deterioration. This project was designed with the primary objective of eliminating the need for salting by providing heat inside an enclosure under the deck. In case the primary objective was found to be impractical, a secondary objective of improving both motorists and maintenance personnel warning systems was sought. The experimental warning systems consisted of a sign which is readable only when illuminated, three different ice detecting systems and a telephone relay system. The results show: 1. Heating is economically comparable with the overall cost of salting and repairing the attendant deck deterioration; 2. Motorist reaction to an "icy bridge" warning sign is poor; 3. Ice detecting systems tested cannot be relied on to detect frost on bridge decks in the California valley area.

**17. KEYWORDS**
Bridge deck icing, bridge deck frosting, bridge deck heating, ice detectors, motorist warning sign, maintenance patrol warning, all weather roads, bridge safety

**18. No. OF PAGES:**
74

**19. DRI WEBSITE LINK**
http://www.dot.ca.gov/hq/research/researchreports/1971/71-45.pdf

**20. FILE NAME**
71-45.pdf

STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
BRIDGE DEPARTMENT



# BRIDGE DECK FROSTING VALLEY ENVIRONMENT

## Final Report

November 1971





h
on,
on

STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
BRIDGE DEPARTMENT

# BRIDGE DECK FROSTING

## VALLEY ENVIRONMENT

FINAL REPORT

Research conducted by C. F. Stewart, Bridge Department,
and
A. Sequeira, Materials and Research Department,
under the direction of
G. D. Mancarti, Bridge Department

621110

HPR PR-1(9) B-4-2

J. E. McMahon, Assistant State Highway Engineer - Bridges

J. L. Beaton, Materials and Research Engineer

Sam Helwer, Deputy State Highway Engineer

November 1971

In Cooperation with
The U. S. Department of Transportation

R&D No. 8-71



71-45

REFERENCE: Stewart, C. F., Sequeira, A., "Bridge Deck Frosting - Valley Environment," State of California, Business and Transportation Agency, Department of Public Works, Division of Highways, Bridge Department, Research and Development No. 8-71, November 1971.

ABSTRACT: Preferential frosting of bridge decks in California's moderate climate valley areas is a hazard to unsuspecting motorists. Salting to prevent this frosting causes premature deck deterioration. This project was designed with the primary objective of eliminating the need for salting by providing heat inside an enclosure under the deck. In case the primary objective was found to be impractical, a secondary objective of improving both motorists and maintenance personnel warning systems was sought. The experimental warning systems consisted of a sign which is readable only when illuminated, three different ice detecting systems and a telephone relay system. The results show: 1. Heating is economically comparable with the overall cost of salting and repairing the attendant deck deterioration; 2. Motorist reaction to an "icy bridge" warning sign is poor; 3. Ice detecting systems tested cannot be relied on to detect frost on bridge decks in the California valley area.

KEY WORDS: Bridge deck icing, bridge deck frosting, bridge deck heating, ice detectors, motorist warning sign, maintenance patrol warning, all weather roads, bridge safety.

ACKNOWLEDGEMENT: The authors are indebted to Highway Maintenance Superintendent, J. J. Quinn and and Highway Maintenance Foremen J. W. Cameron and J. F. DeGusta for their outstanding cooperation, counsel and continued interest during this project and to many other highway maintenance men for their contribution towards it. We are also indebted to Materials and Research Department Representatives R. L. Johnson and S. M. Muraki for their assistance in installing and operating the instrumentation. The research could not have been conducted without the able assistance of these people.

TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES



## APPENDIX A

BRIDGE DECK FROSTING - VALLEY ENVIRONMENT

November, 1971

PROBLEM

In California's Central Valley Area, where the elevation is generally less than 100 feet above sea level and the temperature seldom falls below 20°F, flash frost forms on bridge decks but not on approach roadways. This spot frosting becomes a hazard to unsuspecting motorists. An increase in speed and volume of traffic on modern freeways has caused a sharp increase in multi-car accidents in the last few years due to this phenomenon.

The present motorist warning system of impending frost danger is a standard "Slippery When Wet or Frosty" metal sign, Figure 1, which is sometimes illuminated at night by a flare pot.


Standard Motorist Warning Sign

FIGURE 1

This type of sign is ineffective, primarily because it is continuously visible to the motorist, even in the summer time, and as such becomes an accustomed standard fixture along the roadway. When the sign is used exclusively for frost warning, some maintenance people try to restrict its visibility to periods of actual hazardous conditions by covering it or turning it away from sight when the hazard does not exist. But since frosting is almost impossible to predict, even this method leads to ineffectiveness of the sign due to its frequent cry of "Wolf" by often being exposed when there is no frost.

A generally accepted theory is that in mild winter areas, where approach pavements do not frost, decks on boxed or enclosed spans would be less susceptible to frosting than would decks on open girder type spans. The theory is supported by the assumption that the deck on boxed type spans is kept warmer by one or both of the following methods: 1) The entrapped air acts somewhat like soil under a pavement and through conduction provides warmth to the deck surface; and, 2) the enclosure prevents convection heat loss at the deck's lower surface to cold winds blowing under it, and thereby makes heat available to replace that lost at the surface to the wind.

Since frosting is intermittent--it occurs an average of only 5 to 7 times annually in California's Central Valley Area--regular salting patrols are not maintained. This leaves maintenance forces under a handicap in not being on the spot when needed due to their inability to predict when or where frost will form.

The frosty bridge deck problem in California's Central Valley area is usually handled by one of the following procedures:

1. When there is a high potential for frosting, a crew will stand by to apply a salt-sand mixture to bridge decks as necessary.

2. The Highway Patrol informs local maintenance personnel after frost has formed on decks.

3. A frost preventive saline solution is periodically sprayed onto the decks. Each application is effective for approximately three days. (figure 2)

Applying saline solution to a bridge deck
Figure 2

Adverse ramifications of these procedures are:

1. Bridge deck salt-sanding is an additional task to valley maintenance personnel and results in extensive overtime work as frosting usually occurs before the normal working day begins.

2. Bridge deck salt-sanding in a valley environment is usually done under the hazardous conditions of darkness, foggy weather, and high speed traffic. (The latter is usually more of a hazard to valley salting crews than mountain crews because of the valley motorist's unawareness of the frost or slippery deck problem).

3. When highway patrolmen report frosting it usually means the decks will have been slippery for considerable time before maintenance personnel arrive to salt-sand.

4. The saline solution preventive method accelerates deck deterioration.

5. Regardless of the application method, salt used to combat frost is causing deterioration in decks that have heretofore been maintenance free.

Basically the valley bridge deck frosting problem falls into two areas:

1. Safety (Motorist and Maintenance).

2. Premature deterioration.

## RESEARCH

The primary objective of this research was to study means of eliminating the frosting hazard by heating the deck from underneath.

The secondary objective was to improve motorist and maintenance warning systems should the heating concept prove impractical or less than 100% effective.

The research consisted of:

1. Enclosing the underside of six open girder spans to form simulated box girder spans;
2. Providing heat in three of them;
3. Providing a motorist warning sign which is readable only when illuminated;
4. Installing telephone relay systems to local maintenance control centers;
5. Conducting visual observations on decks of several box and open girder superstructures during periods of potential frosting; and,
6. Experimenting with a non-corrosive deicer.

The sign and telephone relay systems were activated by frost detecting systems with sensors embedded in the deck.

### Enclosures

Two spans of each of three structures were enclosed by attaching one inch thick urethane foam sheets to the bottom of girders. (Figures 3, 4 & 5) The superstructure types were: Steel, reinforced concrete "T" and pre-stressed"M". Mastic between all joint sections made the enclosure airtight. Low resistance electrical heating cables provided heat in one of the two spans so enclosed on each structure.

INSTRUMENTATION
for
MERCED RIVER BRIDGE

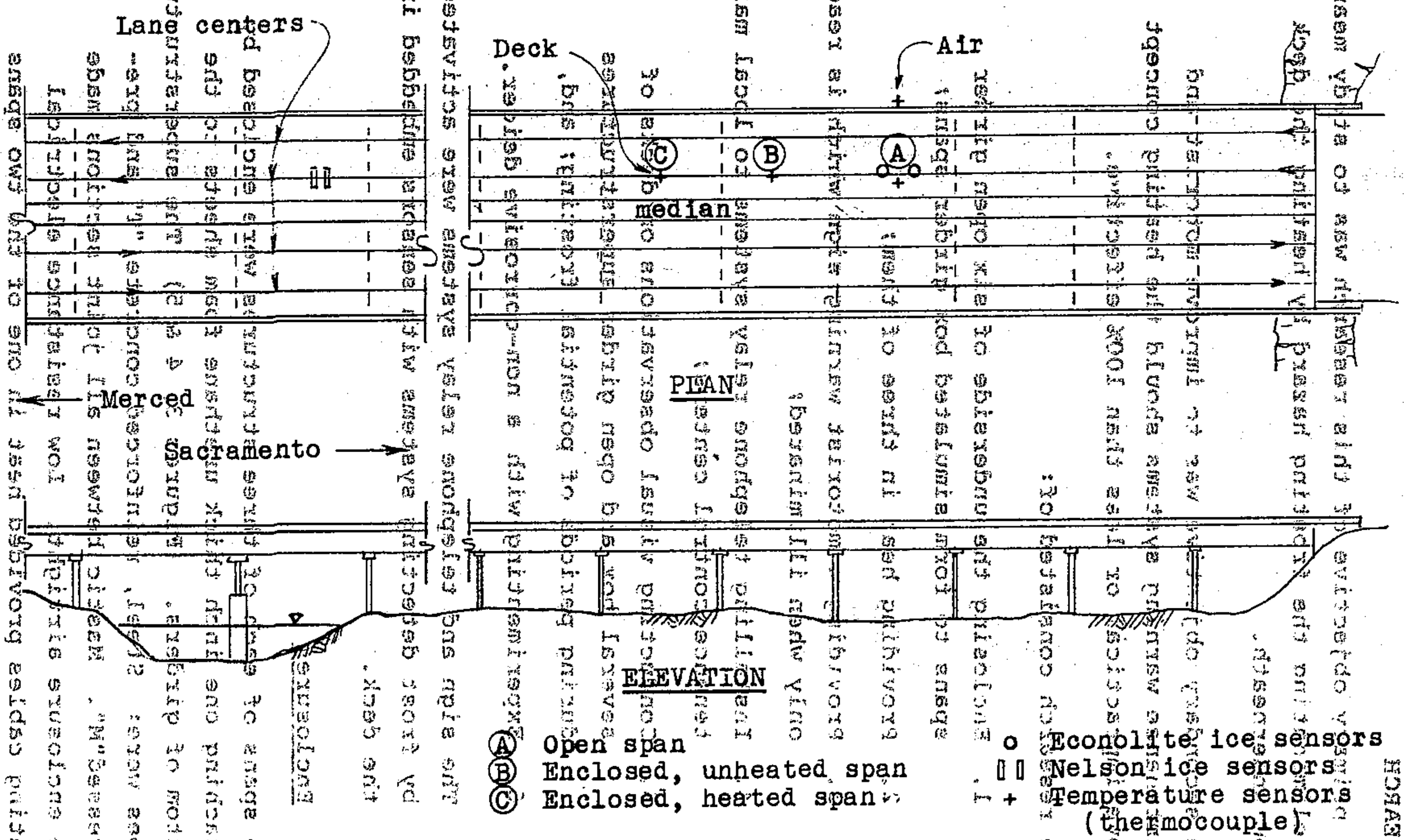
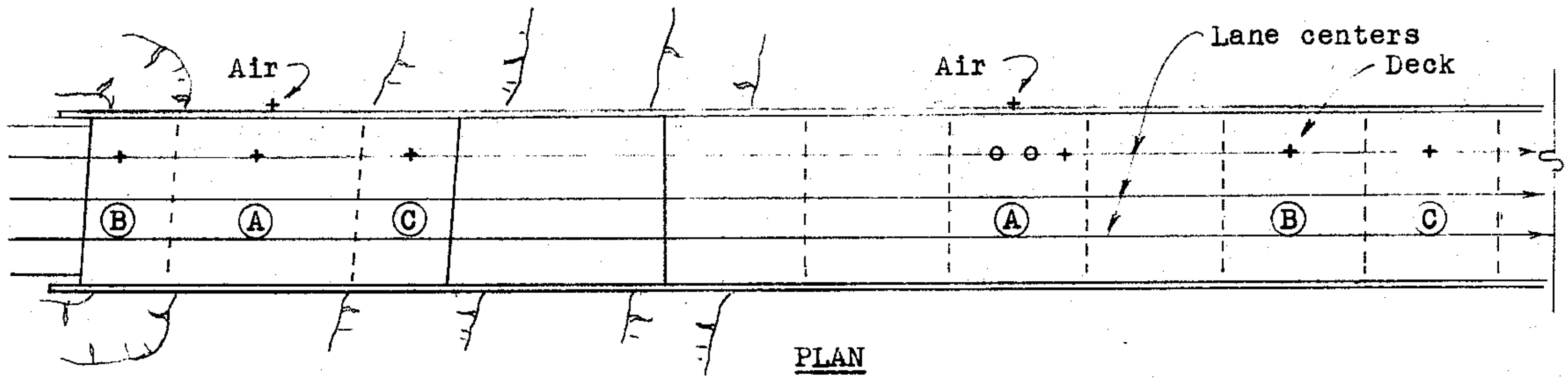
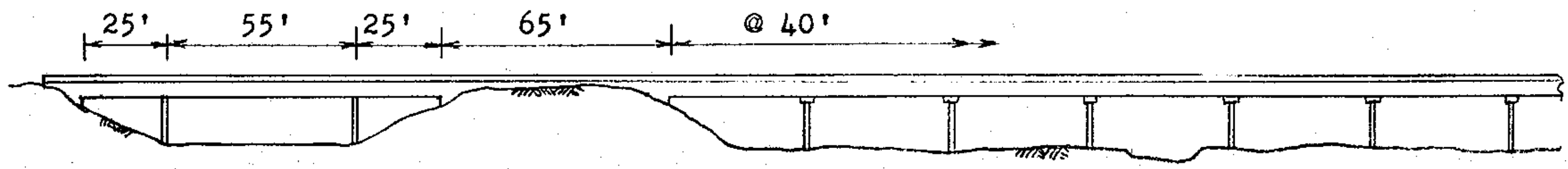



Figure 3

INSTRUMENTATION
for
WEBSTER ST. OC and YOLO CAUSEWAY




PLAN

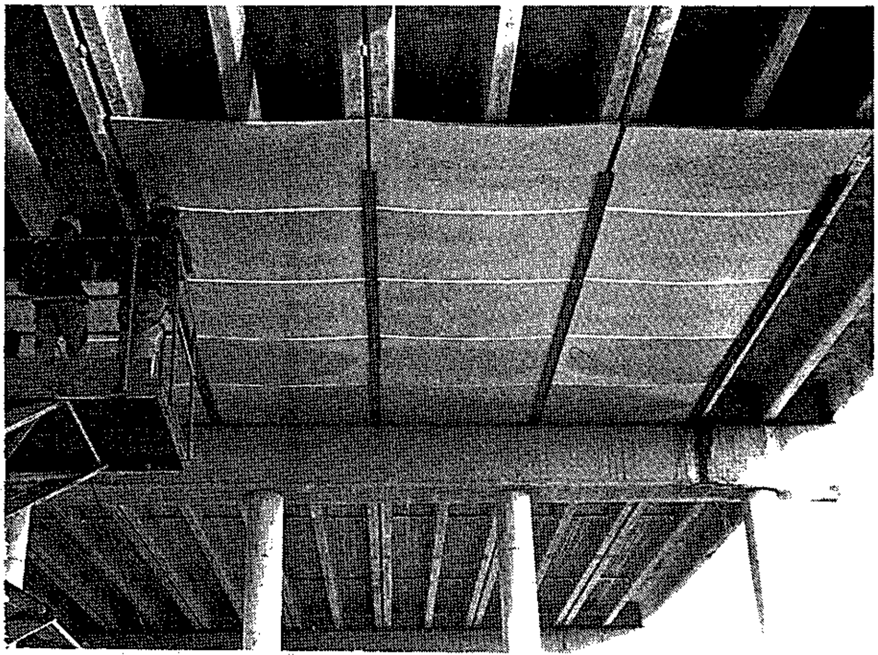



ELEVATION

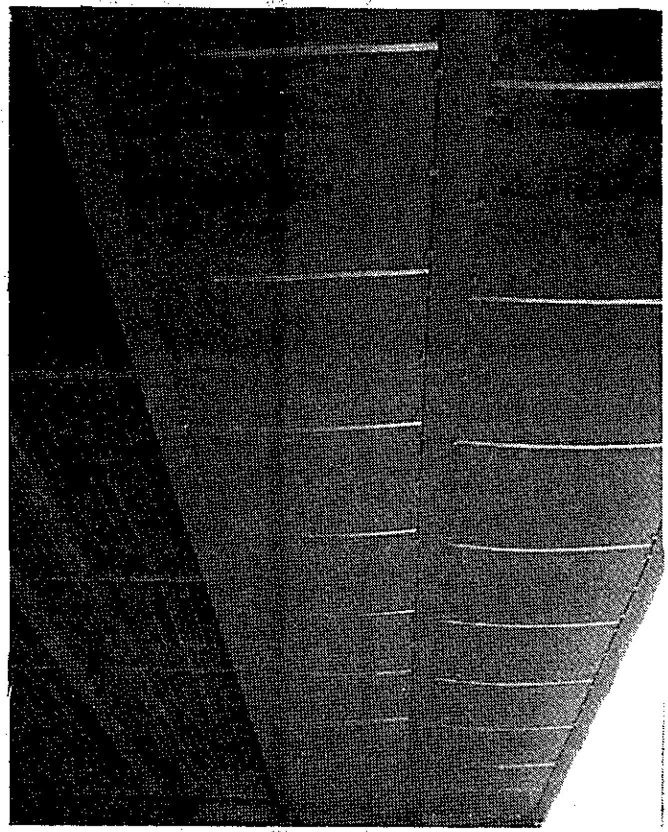
LEGEND

| | | | |
|---|---|---|---|
| Ⓐ | Open span | o | Holly ice sensor |
| Ⓑ | Enclosed, Unheated span | + | Temperature sensor (thermocouple) |
| Ⓒ | Enclosed, heated span | | |

Figure 4



Prestressed
"M" Girders



Note heating
cables in background
span of top photo
and left bays of
bottom photo

Steel Girders

Figure 5

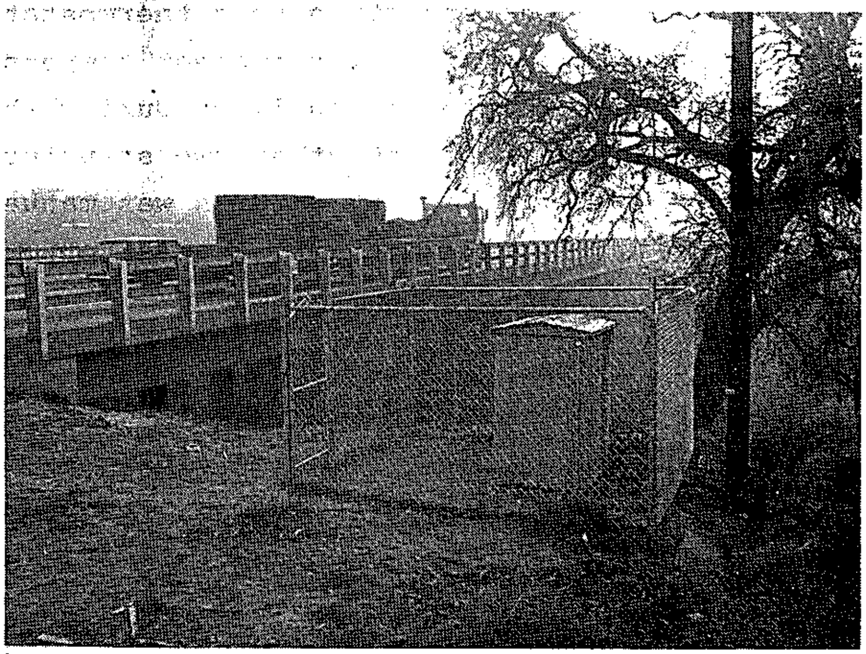
Heat was controlled on one structure by a thermostat that turned on the power when the outside ambient temperature was below 38° F. Heat was continuously on during the test period in the heated spans of the other two structures. The amount of heat furnished at all structures was manually controlled from 2-1/2 to 11 watts per square foot of deck area.

Thermacouples were placed in the surface and soffit of the deck in the enclosed spans and an adjacent unaltered span, in the open space of the enclosed cells, and in the air alongside the bridge. Honeywell 20-point recorders continuously recorded the temperatures on a 5-minute cycle from midnight to 10:00 a.m. each day during the three months of potential frosting: December, January and February. The Instrumentation shed is shown in Figure 6. Sand, without salt, was used to combat frost on the experimental structures during the two winters of the Study.

<u>Frost Detectors</u>

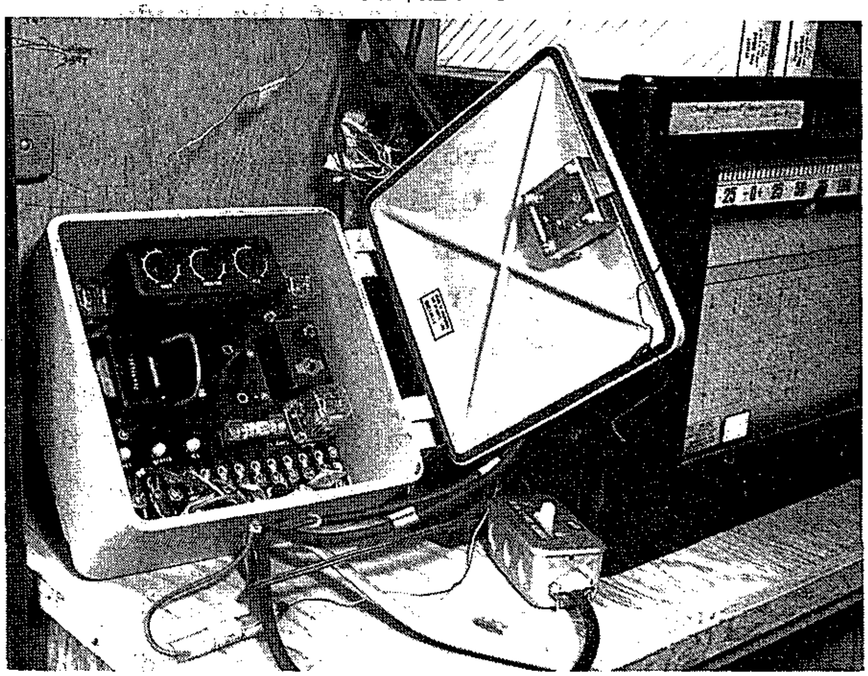
The Nelson Snow Melter Control, Econolite Ice-Moisture Detector and Holley Ice Condition Detector were all used in this study. Sensing transducers of the detectors were placed in the bridge deck flush with the surface, in the center of the inside traffic lane. The detectors were connected to the motorist warning sign and to maintenance telephone relay systems. Activation of the ice detectors were also monitored by the Honeywell temperature recorders. (Figure 7)

All systems employ the same basic logic, that is, they measure conductance between a set of electrodes mounted in each of two sensors placed in the deck. A heater, electrically controlled to turn on at 35°, in one set prevents moisture that is present from freezing. Hence, should conditions be favorable for icing, moisture between



Instrumentation Shed

Figure 6



Econolite controls and
Honeywell 20 point recorder

Figure 7

one set of electrodes will freeze but will remain liquid between the other set. Since ice has a much lower conductance than does water, a comparison of conductance measurements will show: 1) if moisture is present; and, 2) if ice is present. Also the unheated sensor detects temperatures below 32°.

The Nelson unit has one set of electrodes in a rectangular housing and a thermostat, factory set at 32°, in a similar housing. Electrodes for the Econolite and Holley are in two separate cylindrical housings. (Figure 8)

The Holley system reportedly also anticipates icing. It does this by measuring and comparing the relative humidity and ambient and deck surface temperatures. Its electronic logic is set to warn of imminent frost when the relative humidity to saturation differential is slightly higher than the deck surface to ambient temperatures differential.

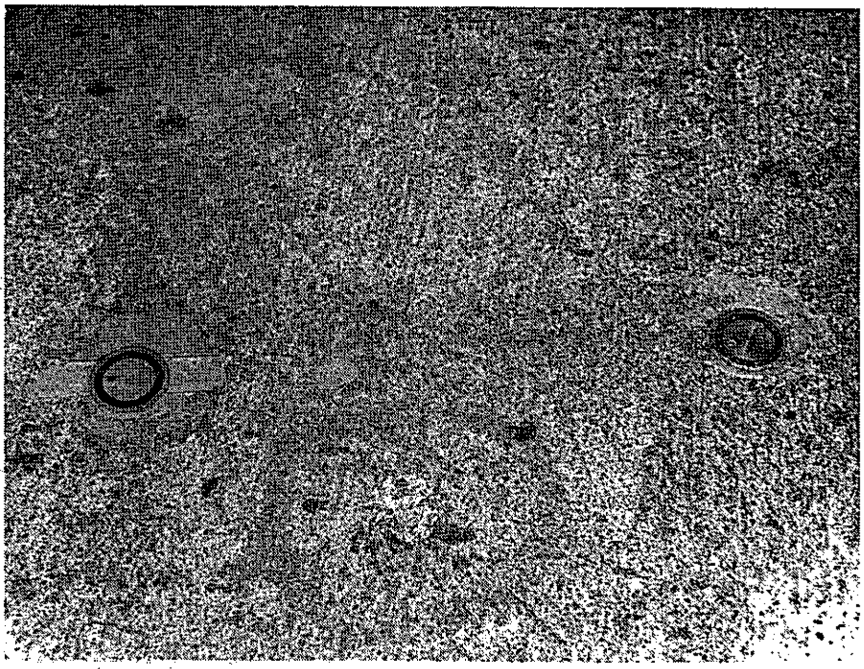
Motorist Warning

An extinguishable message sign was installed on an approach 600 feet from one of the bridges. Flashing fluorescent tubes illuminated the 8-inch high "ICY BRIDGE" letters of the sign from behind. When the tubes are not lit, the letters blend in with the blank face of the sign, thus making the message indiscernible when the sign is "Off". (Figure 9)

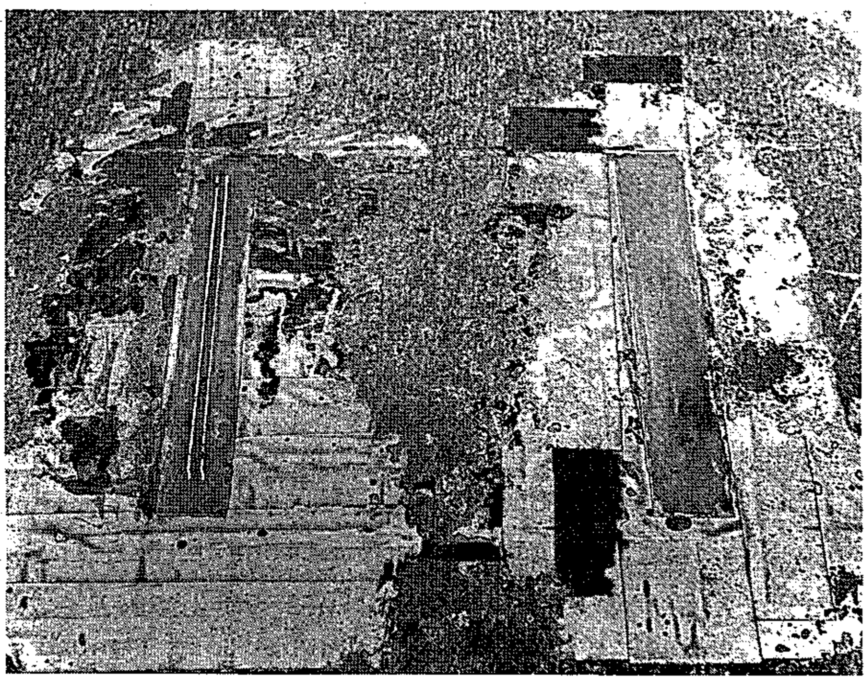
Maintenance Warning

The frost detecting systems were connected, through telephone relays, to a buzzer and light signal mounted in a local Highway Patrol Communication Center in one area and in a continuously manned Bridge Tender's Office in another. The buzzer could be turned off manually, but the small light would remain on as long as the ice detecting system was active. Local highway maintenance personnel were notified when a system was activated.

DECK SURFACE TRANSDUCERS

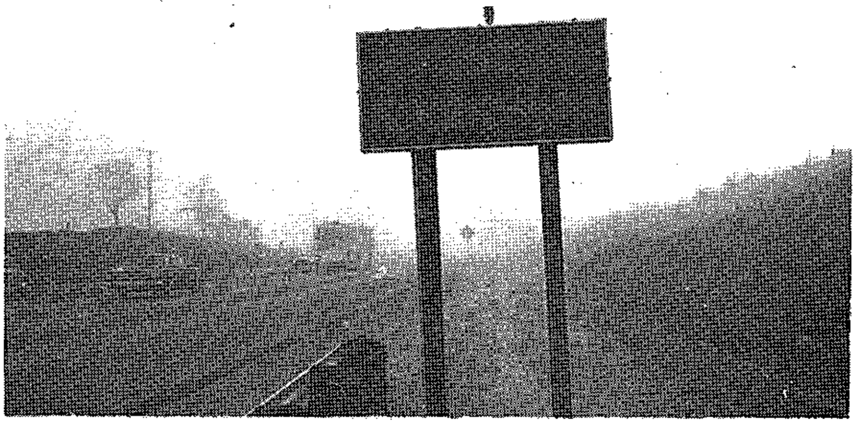


ECONOLITE (Transducers for the Holly system are similar)



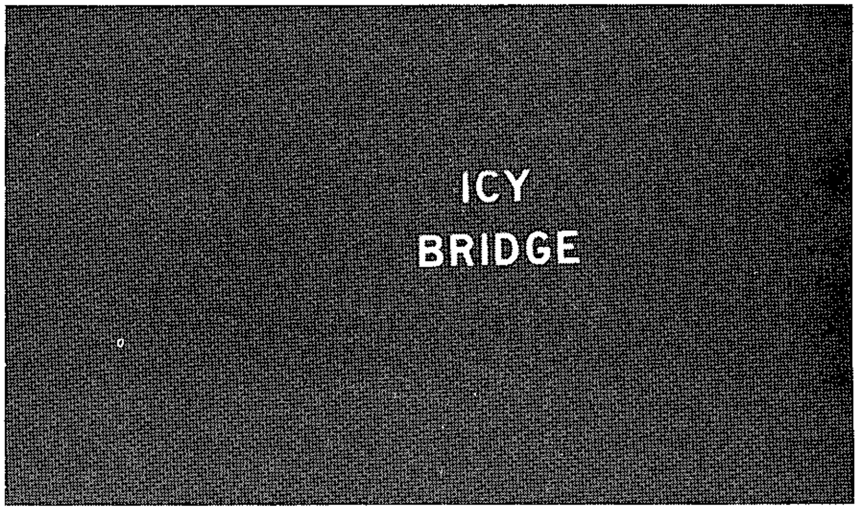
NELSON

Figure 8



OFF


ON
(Day)




ON
(Night)

Figure 9

## Superstructure Type

With an objective of determining if frosting frequency is affected by superstructure type, visual observations were made on 56 structures during two winters when conditions were conducive to frosting. The superstructure types and number of each included in the observations were: Reinforced concrete box girders (23), Reinforced concrete "T" girders (11), prestressed "I" girders (4), Steel girders (14), and reinforced concrete slab (4). The structures were located in the Fresno, Los Banos and Modesto areas of Central California.

## Non-Corrosive Deicers

In their separate studies of non-corrosive deicers, Conrardy 3 and Boies 11 found the fertilizer produce urea to be very effective for melting ice at temperatures down to 25° and to have a very low corrosive rate. Snow seldom falls in the central and lower California Valley areas; hence, the greatest need for a deicer in these areas is to prevent or melt frost rather than snow or ice. Since the temperature in these areas is seldom below 20°, it appeared that urea would be an effective material for combating the frost problem and was, therefore, tried on a limited basis in three different areas. In all three areas the material was used as a frost preventive in that it was applied the day before anticipated frost. In two areas the approximately 1/16-inch diameter prills were dissolved in water and the solution sprayed on the bridge deck. In the other area the prills were broadcast onto the deck along with a fine spray of water.

## RESULTS

### Enclosures

Typical temperatures recorded for the air, deck surface over the enclosed heated span, deck surface over the enclosed but not heated span and the deck surface over the control span were plotted for various days and are shown in Appendix A. Little temperature data are given for Yolo Causeway and Webster Street because (1) very few below freezing days occurred during the experimental period in their area, and, (2) malfunctions in the recording equipment caused erratic readings when below freezing days did occur.

Average temperature differentials, as shown on the plots in Appendix A, occurring between the hours of 5:00 and 7:00 a.m. between the heated and open spans, and enclosed but not heated and open spans are given in Table 1. These data show that for decks without asphalt concrete surfacing, the surface temperature over a span heated with 11 watts per square foot of deck area is about 10 degrees higher than it is over an open span. Also, for decks with asphalt concrete surfacing the temperature differential is about 7 degrees when 10 watts per square foot is applied to the heated span. Why the heat transfer efficiency was less for asphalt concrete surfacing was not discernible during this test.

As can be seen in the Appendix A plots, the deck surface temperature can be either above or below that of the air during low temperature periods. This fact reduces the efficiency of anticipatory detecting systems which require a deck temperature to be several degrees lower than that of the air for activation of their logic systems.

A comparison of the Table 1 temperature differentials shows that enclosing the span has little effect on the surface temperature. Hence, under similar environmental conditions, there should be no difference in frosting frequency between box girder and open girder type structures.

## Frost Detectors

Bridge deck frosting or icing occurs on the average of about 5 to 7 times annually in California's Central Valley area. With this low occurrence frequency it was difficult to adequately and accurately test the ice or frost detectors. On most occasions, however, when deck frosting did occur, as detected by visual observation and by feel of a car being driven over the deck, none of the three makes of detectors tested reacted to show frost.

Visual observations during the few times frost did occur revealed some facts which probably greatly influenced the performance of the ice detectors.

In the California Central Valley area, cold temperatures are usually accompanied with low humidity. When this occurs, the dew point (temperature at which moisture begins to collect on the surface) can be below the freezing point of water. In fact, the dew point can be as low as 25° F. Since the temperature during our test period was seldom below this figure, it is conceivable that we often had dew points lower than the lowest air temperature. If this did occur it would have severely hampered the performance of the type of detectors tested. These detectors work on a principle which requires the presence of moisture on one logic sensor when there is ice or frost on the other for their combined logic system to declare the presence of ice or frost. To preclude the formation of ice on the logic sensor designed to monitor whether or not moisture is present, a heating element is built into it. This heating

TEMPERATURE DIFFERENTIALS

| STRUCTURE | HEAT - WATTS/ft 2 | AVERAGE TEMPERATURE BETWEEN 5:00 & 7:00 a.m. | | | | | |
|---|---|---|---|---|---|---|---|
| | | AIR | DECK* HEATED | DECK* INSULATED | DECK OPEN | Δ° HEATED - OPEN | Δ° ENCLOSED - OPEN |
| Merced | 11 | 26 | 35 | 26 | 25 | 10 | 1 |
| River | 11 | 26 | 30 | 23 | 25 | 5 | -2 |
| | 11 | 30 | 37 | 28 | 28 | 9 | 0 |
| (6-5/8 | 11 | 31 | 39 | 35 | 33 | 6 | 2 |
| inch | 11 | 30 | 39 | 30 | 30 | 9 | 0 |
| PCC | 11 | 30 | 42 | 34 | 33 | 9 | 1 |
| Deck) | 11 | 31 | 42 | 34 | 33 | 9 | 1 |
| | 11 | 31 | 38 | 30 | 30 | 8 | 0 |
| | 11 | 28 | 36 | 27 | 26 | 10 | 1 |
| | 11 | 24 | 35 | 26 | 25 | 10 | 1 |
| | 11 | 28 | 38 | 27 | 26 | 12 | 1 |
| | 11 | 25 | 36 | 26 | 25 | 11 | 1 |
| | 11 | 24 | 38 | 28 | 27 | 11 | 1 |
| | 11 | 27 | 37 | 26 | 25 | 12 | 1 |
| | 11 | 23 | 35 | 25 | 25 | 10 | 0 |
| | 11 | 21 | 33 | 23 | 22 | 11 | 1 |
| Yolo | 5 | 30 | 37 | 34 | 33 | 4 | 1 |
| Causeway | 5 | 31 | 37 | 33 | 32 | 5 | 1 |
| (5 inch | 10 | 33 | 42 | 37 | 37 | 5 | 0 |
| PCC Deck | 10 | 35 | 42 | 35 | 35 | 7 | 0 |
| and 2-1/2 | 10 | 33 | 41 | 34 | 34 | 7 | 0 |
| inch AC | 10 | 31 | 41 | 33 | 33 | 8 | 0 |
| surfacing) | 10 | 31 | 41 | 31 | 31 | 10 | 0 |
| Webster | 3.5 | 30 | 37 | 31 | 31 | 6 | 0 |
| St OC | 3.5 | 30 | 35 | 30 | 30 | 5 | 0 |
| (6" inch | 7.0 | 32 | 45 | 32 | 33 | 12 | -1 |
| PCC Deck) | | | | | | | |

*Underneath portion of two spans enclosed with urethane foam placed at the bottom level of the girder. Heat provided in one span, no heat in the other.

Table 1

element keeps the sensor about 34°. Thus, under the given condition of a below 32° dew point and above 32° temperature of the sensor, moisture will not collect on the sensor. At the same time, moisture will collect and crystalize on the deck if it is at or below the dew point temperature (this temperature has already been stipulated to be below 32°). Hence, frost forms on the deck but the detecting system is fooled because the temperature of its moisture detecting sensor is higher than the dew point.

The effectiveness of an anticipatory system can be greatly reduced in our test area by the fact that frequently frosty conditions materialize rapidly. As mentioned earlier, in this area cold temperatures are usually accompanied with low humidity. Occasionally, however, a sudden shift in wind conditions causes an immediate rise in humidity and thereby causes an immediate combination of factors favorable for frosting. Often this change is so sudden that there is little time between activation of the anticipatory system and the detecting system.

<u>Motorist Warning</u>

Motorists' reaction to the "ICY BRIDGE" warning sign when it was flashing was documented on four occasions by a two-man team. One member was stationed approximately 100 feet in front of the sign, and well off the shoulder area to minimize distraction, while the other was near the bridge abutment, partially shielded from view by an elevation differential and a guard rail. Communications between the two was provided by walkie talkies. The team recorded any discernible evidence of reaction by the motorist to slow his vehicle such as brake lights coming on or motor deceleration. Reaction by applying the brakes was easy to determine. Reaction by motor deceleration was also easy to determine on trucks, but was rather difficult on cars.

The motorist was given credit for reacting whenever there was not clear cut evidence to the contrary. Vehicles approaching the area at below average speed were not included in the observations. Pickups were counted as cars; buses were counted as trucks.

During the observations, the ambient temperature was low enough for frosting, but even though it did form on the railing and on adjacent shrubbery, frost did not form on the deck. In order to conduct the observations, the sign was turned on manually. Since there was ample evidence of frosting, the fact frost did not form on the deck should not have affected motorists' reaction to the advanced flashing warning sign in preparing for the upcoming danger; hence, it also should not have affected the observation results.

The results were rather disappointing. They ranged from a low reaction by motorists of only 24% of 105 cars and 23% of 60 trucks to a better but disappointing high of 56% of 176 cars and 66% of 34 trucks.

There was one observation with a higher percent reaction by motorists in cars, 62% of 13, but due to the small number counted it is not considered as truly representative. This observation was made when the visibility at the beginning was a little better than 500 feet, but gradually dropped to less than 500 feet. Under these conditions, most of the traffic was traveling rather slow as it approached the sign and became slower as the visibility decreased. Consequently there was a lot of subjectivity in selecting which vehicles should be included in the observation. After 35 minutes of observation the number of vehicles traveling too slow to be included outnumbered the faster ones better than 2 to 1. The observation was, therefore, terminated. The results are presented to show that even in very adverse conditions some motorists pay no heed to warning signs.

## DRIVER REACTION TO "ICY BRIDGE" WARNING SIGN

| Time | Temp | Weather | Visibility | DRIVER REACTION | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | CARS | | | | TRUCKS | | | |
| | | | | Deceleration Brake Lights | | No Reaction | % Reaction | Deceleration Brake Lights | | No Reaction | % Reaction |
| | | | | On | Off | | | On | Off | | |
| 0525 — 0630 | 30° | Light fog | Very good | 1 | 24 | 80 | 24 % | 3 | 11 | 46 | 23 % |
| 0515 — 0635 | 28° | High Overcast | Un-limited | 1 | 33 | 42 | 45 % | 5 | 16 | 51 | 29 % |
| 0750 — 0830 | 30° | Foggy | 1000ft. | 23 | 72 | 75 | 56 % | 1 | 22 | 12 | 66 % |
| 0600 — 0635 | 21° | Foggy | 500ft. | 3 | 5 | 5 | 62% | 2 | 10 | 10 | 55 % |

Table 2

Of three school buses that approached the area when visibility was 1000 feet, only one driver made a discernible reaction; he applied his brakes after he was on the bridge. In retrospect, concurrent observations should have been made on the other approach to the bridge. This approach has a standard "SLIPPERY WHEN WET OR FROSTY" sign, illuminated by a flare pot. Such an observation would have yielded a fairly accurate comparison of effectiveness between the two sign types.

### Maintenance Warning

The telephone relay systems operated very effectively in that they responded whenever an ice detecting mechanism indicated frost had occurred. This type of system appears, however, to be a very ineffective method of controlling deck frosting. The time frost remains on decks in California's Valley area is often as brief as 30 minutes. In most cases, it would take almost this much time for a salting crew to assemble and travel to the site. Consequently, in most cases the frost would be gone before a crew arrived to salt if the telephone relay system was relied on as a maintenance warning device.

### Superstructure Type

Decks of the 56 structures included in this phase of the study were inspected by either a foreman or leadman of the highway maintenance crew in the respective areas whenever there was a potential for frosting. They recorded any evidence of frost on either the railing or deck. All structures were salted whenever there was evidence of deck frosting. This practice probably reduced the frosting frequency as it gradually built up a salt residue in the deck which no doubt lowered the required deck temperature for frosting to occur.

A true study of superstructure influence on frosting can only be made if all other variables such as traffic, humidity, temperature, wind, clearance underneath, salting frequency, etc., are uniform. The ideal uniformity of outside variables is impossible to find on a sufficient number of existing structures to make such a study. The only alternative is to inspect a large number of structures and rely on average results as an indicator.

A two-year visual observation of the 56 selected structures indicates that the environment in which the structure is located has much greater effect on deck frosting frequency than does superstructure type. Table 3 compares frosting frequency of structure types with objects crossed. Table 4 gives the average frosting frequency of the various types of structures. A definition of the abbreviations for structure types used in the two tables is given in Table 4.

The results indicate that structures over water are much more susceptible to frosting than are those over either railroads or roadways. There is little difference in frosting frequency between structures over railroads and roadways.

The results are surprising in that they show decks on steel girders frost up less frequently than do those on other type girders. This is contradictory to reports by maintenance personnel that historically they have had a greater frosting problem with steel girdered decks than with other types. Perhaps a major reason for the past apparently one sided adverse performance of steel structures is that, until recently, there were more of them than other types built in areas conducive to frosting, i.e., over water.

EFFECT OF OBJECT CROSSED ON DECK FROSTING FREQUENCY

| STRUCTURE TYPE* | OBJECT CROSSED | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | WATER | | | RAILROAD | | | ROADWAY | | |
| | Number Observed | Times Frosty | Average Frequency | Number Observed | Times Frosty | Average Frequency | Number Observed | Times Frosty | Average Frequency |
| PSI | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 15 | 5.0 |
| RCB | 6 | 26 | 4.3 | 2 | 8 | 4.0 | 15 | 16 | 1.1 |
| RCT | 4 | 12 | 3.0 | 0 | 0 | 0 | 7 | 13 | 1.9 |
| STL | 5 | 16 | 3.2 | 2 | 1 | 0.5 | 7 | 2 | 2.9 |
| SLAB | 4 | 20 | 5.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| AVERAGE | 19 | 74 | 3.9 | 5 | 9 | 1.8 | 32 | 4.6 | 1.4 |

*See Table 4

(1967-'68 Winter through December 1968)

Table 3

# EFFECT OF STRUCTURE TYPE ON DECK FROSTING FREQUENCY

| STRUCTURE TYPE | NUMBER OBSERVED | FROSTY OBSERVATIONS | AVERAGE FREQUENCY |
|---|---|---|---|
| PSI | 4 | 15 | 3.7 |
| RCB | 23 | 50 | 2.2 |
| RCT | 11 | 27 | 2.4 |
| STL | 14 | 19 | 1.4 |
| SLAB | 4 | 20 | 5.0 |

## LEGEND

PSI = Prestress "I" girders

RCB = Reinforced concrete box girders

RCT = Reinforced concrete "T" girders

STL = Structural steel "I" girders

SLAB = Reinforced concrete solid slab

All structures had a bare (no overlay) portland cement concrete deck.

Table 4

The box girder type had a slightly less average frosting frequency than did all other types except steel.

Regardless of which frost more or less frequently, the observations show that all superstructure types are susceptible to frosting. Consequently the frosting problem in California cannot be solved merely through use of a particular superstructure type.

The inside passing lane, which normally carries less traffic than the others, was found to be the first to frost. Hence, traffic volume is obviously an important variable in the frosting frequency problem.

## Non-Corrosive Deicers

Urea, whether applied in a solution or solid form, proved to be about as effective in preventing frost as sodium or magnesium chloride solutions. However, it appeared to cause the deck to become overly slippery for some time after its application. Skid tests conducted with Highway Patrol cars were made to compare the slipperiness of urea with sodium chloride solution, plain water and dry pavement. Results of these tests are given in Figure 10. The results did not corroborate the overly slippery claim and more work was planned to develop urea as a non-corrosive deicer. In the meantime the California Division of Highways Materials and Research Department was conducting corrosive studies on several deicing candidates. During these studies, they found urea to be non-corrosive in light or moderate concentrations but highly corrosive in heavy concentrations. As the latter condition will occur after several applications on a bridge deck, interest in further studies of urea as a deicer was lost.

SKID TESTS

| Pavement Surface Condition | Run No. | Skid Length (ft) | | Coeff. of Friction |
|---|---|---|---|---|
| Wet with plain water | 1 | 49.5 | | 82.5 |
| | 2 | 49.5 | | 82.5 |
| | 3 | 48 | | 85 |
| | | | Ave. | 83.5 |
| Urea solution sprayed over damp surface | 1 | 48* | | 85 |
| | 2 | 53 | | 77 |
| | 3 | 52.5 | | 78 |
| 2nd application | 4 | 55 | | 74 |
| | 5 | 59.5 | | 69 |
| | | | Ave. | 75.0 |
| Magnesium Chloride solution sprayed over damp surface. | 1 | 46** | | 84 |
| | 2 | 53.5 | | 76 |
| | 3 | 52 | | 78 |
| 2nd application | 4 | 49 | | 83 |
| | 5 | 51 | | 80 |
| | 6 | 46 | | 89 |
| | | | Ave. | 80.1 |
| Dry | 1 | 55 | | 74 |
| | 2 | 49 | | 83 |
| | 3 | 51 | | 80 |
| | | | Ave. | 79.0 |

Skid tests were made with a 1966 Dodge California Highway Patrol car traveling at 35 mph on 2 year old PCC pavement.

Coefficients of friction were determined from a formula used by the Highway Patrol:

$$f = 0.033\frac{V^2}{S} \quad \text{shere } V = \text{velocity}, \; S = \text{skid length}$$

*Rear wheels started skidding 3' short of test section. Not included in the average.

**Car traveling more near 34 mph. This should not significantly affect friction determination, but nevertheless to keep variable to a minimum it was not included in the averages.

Figure 10

Also, at about the same time, the development of a non-corrosive deicer was removed from the scope of this project and added to another Federal sponsored project being conducted by the California Division of Highways Materials and Research Department. The title of that project is "Evaluation of Non-corrosive Deicing Chemicals." Hence, no further work was done on non-corrosive deicers under this project.

It is interesting to see that from Table 6 cost of materials to salt bridge decks account for only approximately 11% of the total salting cost. This fact becomes very important when a non-corrosive deicer is considered. Most non-corrosive deicers are several times more expensive than sodium chloride. This additional material cost has caused a prejudgment of the non-corrosive concept as uneconomical, whereas in fact, the additional cost of materials would raise the overall salting cost only slightly and the small increase would be more than offset by the consequent reduction in costly deck deterioration repairs.

## DISCUSSION

### Heating Cost

Heat required inside an enclosure under a concrete deck to preclude its surface from frosting is affected by the following variables:

1. Air temperature
2. Wind
3. Humidity
4. Deck thickness
5. Enclosure Efficiency

Of these variables, deck thickness and enclosure efficiency remain constant on a given bridge; hence, heat loss due to these variables is predictable.

On the other hand, the first three listed variables will change from day to day or in fact from hour to hour and cause an unpredictable changing heat loss at the deck surface.

It would be extrememly difficult, if not impossible, to design a heating system with an output capable of coping with fluctuating demands of the changing variables. A very important fact to be considered in such a design is the time element. Time is required to raise the heat inside the enclosure and for conductance of the heat through the slab. The variables, however, can change very quickly, especially wind velocity. Hence, to be effective, a responsive heating system would require an anticipatory unit capable of anticipating the upcoming variable change. Such a device does not exist. There was not sufficient data collected during this research to shed any light on what the heat demands would be for any of the variables. The data did show that a heat supply inside an enclosure of approximately 11 watts per square foot of deck area would raise the deck surface temperature 10°F or more approximately 90% of the time when it was exposed to air temperatures down to 25°. Such a temperature rise would probably be effective in precluding frost at air tempreatures as low as 21° a high percentage of time. This assumption is based on the fact that at one location when the air temperature was at this level, the heated deck was conspicuously dry when the adjacent decks were frosty, and that generally, in California's valley areas the lower temperatures are usually accompanied with low humidity and an attendent low dew point.

Until more data are collected, and to lessen the risk of frosting in the interim, the design of a deck heating system should be capable of delivering an equivalent of 22 watts per square foot of deck area. This is twice the maximum which was available during this research, consequently a good safety margin would be provided against frosting since the 11 watts was 100% effective during the two years it was tested. The higher heat value should be controlled so that it is not activated until the outside air temperature drops to approximately 29°. This should allow more than sufficient time for the additional heat to build up inside the enclosure before it is needed at the surface. Doubling the heat which was available during this research for future applications will not overly increase either the installation or operating cost of a normal operating system. During the two years of this research, air temperature at the two sites (two of the experimental structures were very close together; therefore, could be considered as being at the same site) reached 29° only one time at one and eighteen times at the other. For comparison, air temperature at the sites reached a low between 38° and 30° forty and sixtyone times respectively.

Subsequent to the start of this research, California installed a heating system under a steel orthotropic deck. The structure is located in a mild valley environment where regular concrete decks frost infrequently. The steel deck, however, frosted frequently. Salting necessary to combat this frosting not only caused inordinate work by maintenance crews but also caused concern for corrosion of the steel deck. Hence, the heating system was installed during the Summer of 1969 and salting was discontinued thereafter.

The heating system consists of two 240,000 BTU output heaters, one on each end of the structure, with air blowers to disperse the heat. The bottom portion of the enclosure was formed with ribbed steel decking supporting urethane foam insulating sheets. The thermostat controlled system turns on with a full output (480,000 BTU) when the outside air temperature drops to 40° and reduces to 1/4 output (120,000 BTU) when the inside temperature reaches 80°. (This "turn on" temperature appears high and the design engineers are planning on experimenting with lowering it this coming winter, 1971-72). Since the system has been in operation, frost has formed on the deck twice: Once during the initial adjustment period and once during an equipment breakdown. Otherwise, the system has been very effective in preventing deck frosting.

Deck area heated by the system is 9,100 sq. ft. Therefore, the initial heat supplied is 52.7 BTU per sq. ft. The 22 watts proposed as a maximum heat source for concrete decks is equivalent to 74.8 BTU. The system cost $52,000, or approximately $5.71 per sq. ft. Operating cost -- gas and electricity -- during the 1970 year was $332 or $0.036 per sq. ft. This includes standby costs during the warmer months of the year (Table 5). One point of interest in the operating cost figures is that it cost the same for electrical power to disperse the heat (electrical blowers) as it did for gas power to provide it (gas furnances).

The system has not been in operation a sufficient time for accrual of meaningful maintenance cost.

The heating system placed under the orthotropic deck and the operating parameters are similar enough to the requirements of concrete bridge decks in the California valley areas that cost of the orthotropic system could be used as an average estimated cost for heating a concrete deck with little error. In some cases the operating cost could be a little higher, but on the other hand, in some cases the installing cost would be much lower, for instance, on a box girder type structure which already has a built in enclosure. Therefore, for estimating purposes, the cost of a heating system for a concrete deck in California's valley area would be $5.71 for installation and $0.04 per year operating cost per square foot of deck area. An estimated cost of, say $0.02 for maintenance should be a little on the high side. Most of the system should have a service life of approximately 25 years.

POWER BILLS
FOR
HEATING RTE. 680/580 SEP.
(Steel Orthotropic Deck)

| Year | Month (Bill rec'd) | Gas (Heaters) | Electricity (Blowers) |
|---|---|---|---|
| 1969 | Aug | $ 0.85 | $ 1.71 |
| | Sept | 1.20 | 1.71 |
| | Oct | 3.09 | 2.82 |
| | Nov | 0.00 | 0.00 |
| | Dec | 25.21 | 24.56 |
| 1970 | Jan | 26.22 | 22.77 |
| | Feb | 31.65 | 27.85 |
| | March | 27.33 | 26.98 |
| | April | 17.45 | 18.82 |
| | May | 17.63 | 15.97 |
| | June | 9.28 | 5.10 |
| | July | 3.45 | 2.93 |
| | Aug | 3.45 | 2.93 |
| | Sept | 3.68 | 3.99 |
| | Oct | 3.51 | 2.12 |
| | Nov | 5.45 | 7.69 |
| | Dec | 17.54 | 28.33 |
| 1971 | Jan | 54.88 | 67.14 |
| | Feb | 67.41 | 41.02 |
| | March | 55.40 | 31.16 |
| | April | 22.86 | 12.47 |

TABLE 5

## Deck Salting Cost

Salting costs of bridge decks, including labor, equipment and materials, were gathered from six different maintenance superintendents' areas. These costs cover a three-year period and are shown in Table 6. Even though over 95% of the cost data shown represents bridge deck salting costs, it is impossible to calculate from them an expected annual cost to salt a bridge deck in the valley environment. The primary reason for this is that the cost given is for salting between certain limits of designated highway routes, but not all of the bridge decks within these limits are salted the same number of times each year. For instance, those decks located over streams in an urban area are invariably salted any time salting is needed along the route, whereas those located over a city street near a metropolitan area are salted only occasionally. The decks located in between these extremes are salted according to the demands of their environmental area. Heretofore, precise records as to exact structures covered on each salting run have not been kept. In addition, the total square foot area of deck also affects the average salting cost. Generally, the greater the total square foot area of deck along the route, the less cost required per square foot to salt it. This should be expected due to a more efficient use of personnel and equipment afforded by the larger areas.

Although the cost data cannot be used to give an exact annual cost, it is nevertheless presented so as to give some indication of costs to salt valley bridge decks. Table 7 is a breakdown of cost per square foot of area on some of the routes for which the data in Table 6 represents. The wide variability in costs which are expected due to the factors discussed are clearly shown in this table. Without the information needed to apply a proper weighted factor to each cost, the average annual cost cannot be calculated. An empirical evaluation shows that two

FROST PREVENTION COST DATA
(Total Cost)

| Area | Salting Method | FY | COST | | | |
|---|---|---|---|---|---|---|
| | | | Labor | Equipment | Material | Total |
| Madera | NaCl Solution | 66-67 | $ 5,133 | $1,511 | $ 746 | $ 7,430 |
| | Do | 67-68 | 10,044 | 2,410 | 1,334 | 13,788 |
| | Do & NaCl/Sand | 68-69 | 9,259 | 3,274 | 1,378 | 13,911 |
| Visalia | MgCl Solution | 66-67 | 1,893 | 541 | 272 | 2,706 |
| | Do | 67-68 | 4,132 | 1,414 | 579 | 6,125 |
| | Urea | 68-69 | 4,351 | 2,066 | 670 | 7,087 |
| Bakersfield | (Incomplete data) | 66-67 | - | - | - | - |
| | NaCl/Sand | 67-68 | 2,693 | 1,594 | 1,025 | 5,311 |
| | Do | 68-69 | 2,796 | 1,434 | 1,626 | 5,856 |
| Merced | MgCl Solution | 66-67 | 5,188 | 4,495 | 1,145 | 10,828 |
| | Do | 67-68 | 8,803 | 7,106 | 464 | 16,373 |
| | Do | 68-69 | 7,072 | 4,462 | 1,177 | 12,711 |
| Stockton | MgCl Solution | 66-67 | 642 | 200 | 656 | 1,508 |
| | Do | 67-68 | 842 | 232 | 241 | 1,315 |
| | Do | 68-69 | 1,306 | 436 | 397 | 2,139 |
| Modesto | MgCl Solution | 66-67 | 1,248 | 645 | 461 | 2,354 |
| | Do | 67-68 | 2,200 | 1,280 | 634 | 4,114 |
| | Do | 68-69 | 2,658 | 1,523 | 57 | 4,238 |

TABLE 6

FROST PREVENTION COST DATA
(Cost per sq. ft. of deck area)

| FY | Salting Method | Salting Cost | Bridge Deck Area | Cost/ Sq.ft. |
|---|---|---|---|---|
| 66-67 | | | | |
| 67-68 | NaCl/Sand | $1,221 | $ 61,700 | $0.020 |
| 68-69 | Do | 849 | Do | 0.014 |
| 66-67 | | | | |
| 67-68 | Do | 43 | 199,200 | 0.0002 |
| 68-69 | Do | 80 | Do | 0.0004 |
| 66-67 | NaCl Solution | 3,015 | 183,900 | 0.016 |
| 67-68 | Do | 4,594 | Do | 0.025 |
| 68-69 | Do & NaCl/Sand | 4,195 | Do | 0.023 |
| 66-67 | NaCl Solution | 860 | 26,400 | 0.032 |
| 67-68 | Do | 1,593 | Do | 0.060 |
| 68-69 | Do & NaCl/Sand | 1,196 | Do | 0.045 |
| 66-67 | NaCl Solution | 1,082 | 25,600 | 0.042 |
| 67-68 | Do | 1,867 | 53,300 | 0.035 |
| 68-69 | Do & NaCl/Sand | 1,251 | Do | 0.024 |
| 66-67 | MgCl Solution | 1,760 | 132,700 | 0.013 |
| 67-68 | Do | 2,964 | Do | 0.022 |
| 68-69 | Urea | 3,807 | Do | 0.029 |
| 66-67 | MgCl Solution | 600 | 77,200 | 0.008 |
| 67-68 | Do | 1,810 | Do | 0.023 |
| 68-69 | Urea | 2,289 | Do | 0.030 |
| 66-67 | MgCl Solution | 2,232 | 306,700 | 0.007 |
| 67-68 | Do | 3,236 | Do | 0.011 |
| 68-69 | Do | 3,323 | Do | 0.011 |
| 66-67 | MgCl Solution | 1,051 | 276,300 | 0.004 |
| 67-68 | Do | 2,221 | Do | 0.008 |
| 68-69 | Do | 2,660 | Do | 0.009 |

TABLE 7

cents per square foot is an acceptable average annual, salting cost of a structure located in an average valley frosting environment. This figure should be raised for a structure with a small deck area that is located in a severe frosting environment. Conversely, it should be lowered for a structure with a large deck area that is located in a mild frosting environment.

### Heating vs Salting

A cost comparison between enclosure heating and deck salting should include not only installation, maintenance and operating cost, but also a value for safety to the maintenance salting team and the cost to repair decks damaged by salt. Deck heating would eliminate the need for salting teams, therefore, should be given due credit for providing a safer operation. Similarly, salting causes premature deck deterioration and should therefore be monitarily penalized accordingly in a cost comparison.

Quantitative records of accidents involving salting teams could not be found. Hence, assigning a meaningful quantitative value for safety to a method which would eliminate the teams is impossible. Therefore, a qualitative value will have to be used in a cost comparison.

The cost to restore salt damaged decks can be estimated with a fairly high degree of accuracy. So far there have been about 100 salt damaged decks repaired in California. Cost of these repairs have averaged approximately $2.87 per square foot of deck area. Time needed to repair after salting is started on a bridge deck has averaged approximately 11 years. These repairs are considered as temporary expediencies with outright deck replacement an ultimate requirement. Life of the repairs is uncertain but is estimated to be a minimum of 15 years in a valley environment. This estimate is based on the performance history of repairs made on decks built with calcium chloride in the concrete.

There have been 5 salt damaged decks replaced thus far in California. (These decks were not repaired prior to replacement). The average cost of replacement has been approximately $14.30 per square foot. The replacement cost includes a protective seal to prevent salt damage to the new deck.

We therefore, have the following cost figures for comparative purposes (all are per square foot of deck area):

<u>Enclosure Heating</u>

| | |
|---|---|
| Initial: | $ 5.71 |
| Annual Operation: | 0.04 |
| Annual Maintenance: | 0.02 |
| Heating System Replacement: | 5.00 |

<u>Salting</u>

| | |
|---|---|
| Annual Operation: | $ 0.02 |
| Deck Repair: | 2.87 |
| Deck Replacement: | 14.30 |

The normal procedure used in a cost comparison or a cost effectiveness study is to consider a 50 year structure life. Based on an average annual cost amortized over a 50-year period we have:

<u>Enclosure Heating</u>

(Initial + replacement + operating)

$$\frac{5.71 + 5.00 + 0.06(50)}{50} = \$0.28/\text{yr}$$

<u>Salting</u>

(Repair + replacement + operating)

$$\frac{2.87 + 14.30 + 0.02(50)}{50} = \$0.36/\text{yr}$$

Instead of a straight amortization, if we consider the costs on a present worth basis using 5% interest rate and 50-year life we have:

Enclosure Heating

| | | | |
|---|---|---|---|
| Initial: | | | $ 5.71 |
| Annual operation: | 0.04 (18.26)* | = | 0.73 |
| Annual Maintenance: | 0.02 (18.26)* | = | 0.37 |
| Replacement: | 5.00 (0.295)* | = | 1.48 |
| | Total | | $ 8.29 |

Salting

| | | | |
|---|---|---|---|
| Annual Operation: | 0.02 (18.26)* | = | $ 0.37 |
| Deck Repair (in 11 years): | 2.87 (0.585)* | = | 1.68 |
| Deck Replacement (26 years): | 14.30 (0.281)* | = | 4.02 |
| | Total | | $ 6.07 |

*Present worth factor

Thus the more economical choice is dependent on the method used to evaluate the cost. By a straight amortization, enclosed heating is more economical than salting; whereas, by present worth, the economy is reversed. A credit value for safety to maintenance crews applied to the enclosed heating system would tend to narrow the cost differential of the present worth method. This cannot be done because of the lack of data in this area. The figures are sufficiently far apart, however, that the credit factor would probably not significantly alter the results; salting would still be more economical on a present worth basis.

From the closeness of the cost comparison and the fact most figures were determined subjectively, no definite general conclusions can be drawn from the data presently available regarding the most economical frost preventive method. Future comparisons will have to be made on a structure to structure basis. There is a Highway Research Board sponsored research project being done by Midwest Research Institute of Kansas City, Missouri, "Economic Evaluation of the effects of Ice and Snow on Bridge Decks," with an objective of developing a methodolgy, including cost-benefit or cost effectiveness procedures, that can be used to determine the added design or extra maintenance cost justified to prevent or remedy ice or frost on any bridge deck. This study should provide more meaningful cost data, including accident prevention cost than what is currently available.

CONCLUSIONS

1. Type of structure has little influence on the frequency of deck frosting.

2. Object over which the structure crosses -- waterway, roadway, railway, etc. -- has a marked influence on the frequency of deck frosting. The frequency is much greater on structures over water and about the same on structure over roadways and railways.

3. "After-the-fact" type of warning to maintenance crews of deck frosting is ineffective in California's valley areas since the duration of frost is generally shorter than the time for maintenance personnel to assemble and travel to the site.

4. The ice detecting and anticipatory type mechanisms tested are not effective on bridge decks in the California Valley area.

5. Motorists reaction to an illuminated warning "icy bridge" sign is poor.

6. Frost on a bridge deck surface can be prevented by under the deck heating.

7. The cost of heating a deck in the California Valley environment compares favorably with the over all cost of salting and attendant deck deterioration.

8. Bridge deck heating is the only total solution to the bridge deck preferential frosting problem in a valley environment: It eliminates the need of warning systems; it eliminates the need of salting crews; it eliminates salt caused deck deterioration.

## RECOMMENDATIONS

1. Provide heating inside approximately 12 mainline box girder structures in the California Central Valley area.

2. Provide suitable openings in all box girder structures to be built in the valley area, the purpose being to make the addition of future heating facilities a less costly venture should the system continue to show promise. These openings can be provided during construction at little, if any, additional cost.

## IMPLEMENTATION

Openings have already been provided in approximately 6 box girder structures. It is planned to add heating facilities to these and other structures in the near future. Additional observations will be made on the performance of these systems. Future action will be dictated by the results of these observations.

REFERENCES

1. Bourget, L., "Pavement Icing Warning Systems - Laboratory Evaluation of Econolite and Nelson Prototype Devices," State of California, Business and Transportation Agency, Department of Public Works, Division of Highways, Materials and Research Department, January 1967.

2. Forbes, C., C. Stewart, and D. Spellman, "Snow and Ice Control in California, " paper presented at the HRB-CRREL Symposium on Snow Removal and Ice Control Research, Hanover, New Hampshire, April 1970.

3. Conrady, W. P., "Chemical Deicers for Runways," The Military Engineer, No. 374, Nov-Dec 1964.

4. Richard, C. and M. F. Ciemochowski, "Bridge Detector System Predicts Frost and Ice," Rural & Urban Roads, July 1967.

5. Feiler, W. A., "A Study of Cost, Ice Melting and Corrosion Characteristics of Several Chemical Deicers," Monsanto Co. Special Report No. 6573, January 1966.

6. Ziegler, C. M., "Michigan's Experiment in Snow and Ice Removal By Radiant Heat," Michigan State Highway Department, Final Report No. 278, April 1957.

7. Axon, E. O., and R. W. Couch, "Effects of Insulating the Underside of a Bridge Deck," Highway Research Record No. 14, 1963.

8. Graham, M. D., I. F. Rizzuto and J. A. Corbisiero, "Effect of Bridge Deck Insulation on Icing Conditions," Highway Research Record No. 94, 1965.

9. Roy Jorgensen and Associates, "Non-Chemical Methods of Snow and Ice Control on Highway Structures," NCHRP Report 4, 1964.

10. Boies, D. B. and S. Bortz, "Economical and Effective Deicing Agents For Use On Highway Structures," NCHRP Report 19.

11. Butler, H. D., "Study of Electrically Heated Bridge Decks for Ice Prevention." Texas Highway Department.

12. Himmelman, B. F. and M. C. Parsons, "Effectiveness of Anticorrosion Additives in Deicing Salts," Minnesota Department of Highways, 1967.

13. Harris, J. C., J. R. Gibson and D. Street, "Chemical Means for Prevention of Accumulation of Ice, Snow, and Slush on Runways," Monsanto Research Corporation, March 1965.

# APPENDIX A

## TEMPERATURE

## AND

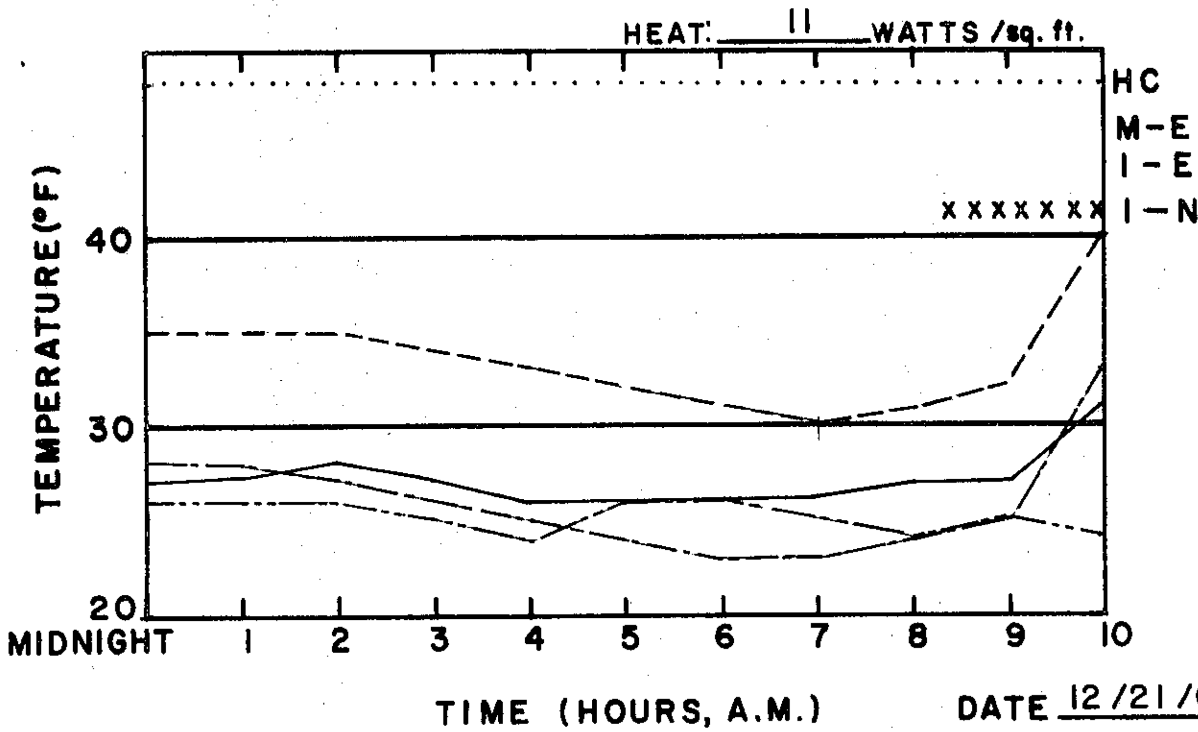
## ICE DETECTION

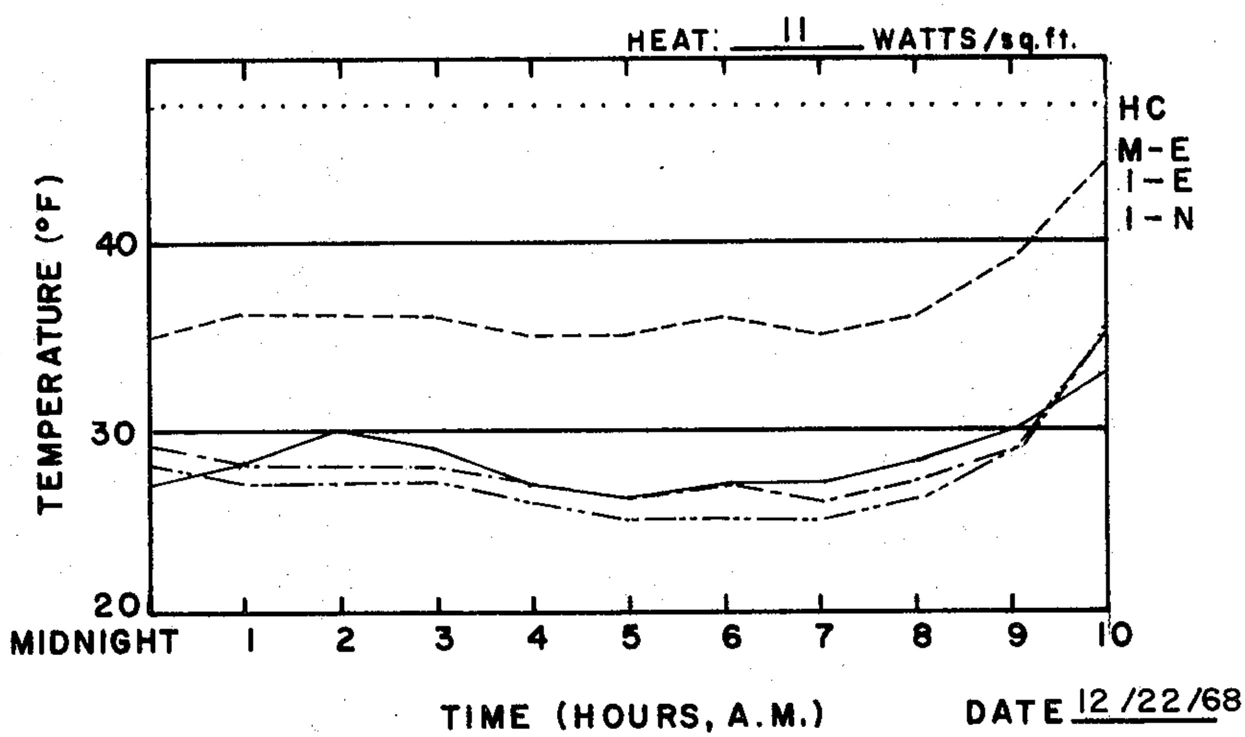
## DATA

# TEMPERATURE AND ICE DETECTION

## MERCED RIVER BRIDGE

| LEGEND | | EVENTS ON | |
|---|---|---|---|
| ———— | AIR TEMPERATURE | HC = HEATING CABLES | · · · · · |
| – – – – – | HEATED CELL DECK TEMP | M–E = MOISTURE – ECONOLITE | o o o |
| —— – —— | INSULATED CELL DECK TEMP | I – E = ICE – ECONOLITE | + + + + + |
| —— · – · —— | UNINSULATED CELL DECK TEMP | I – N = ICE – NELSON | x x x x x |

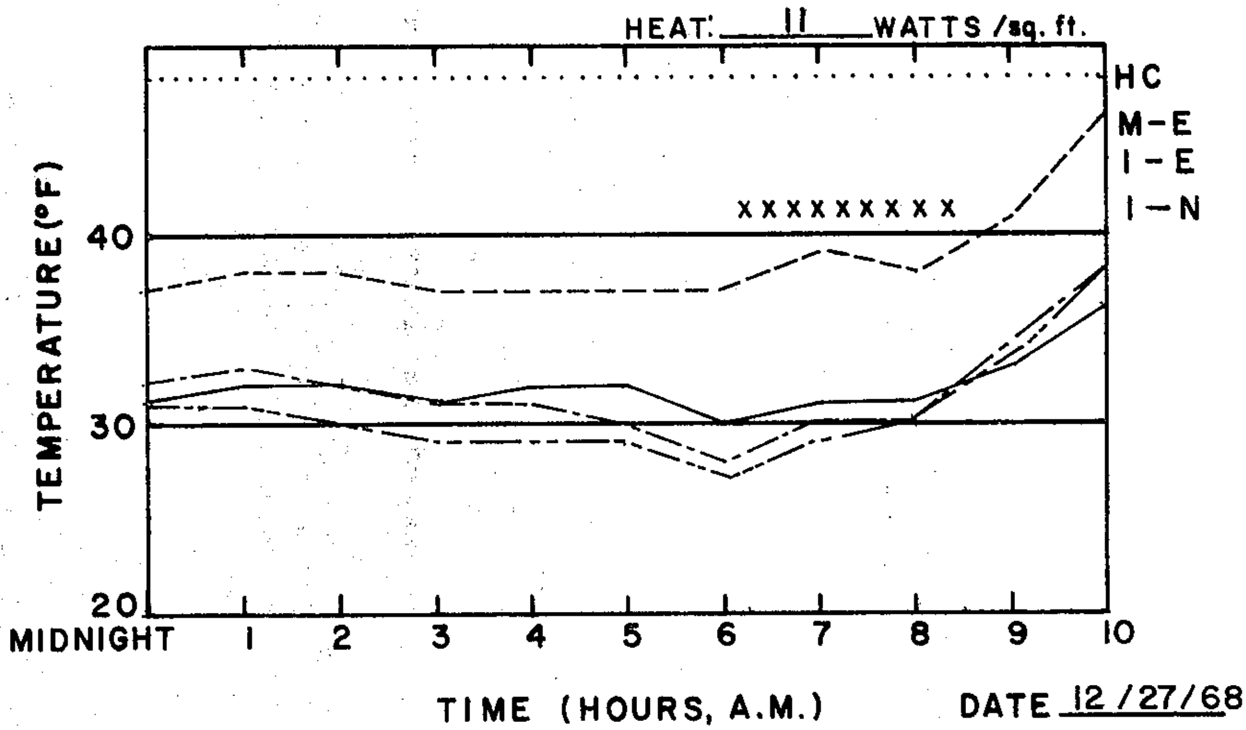


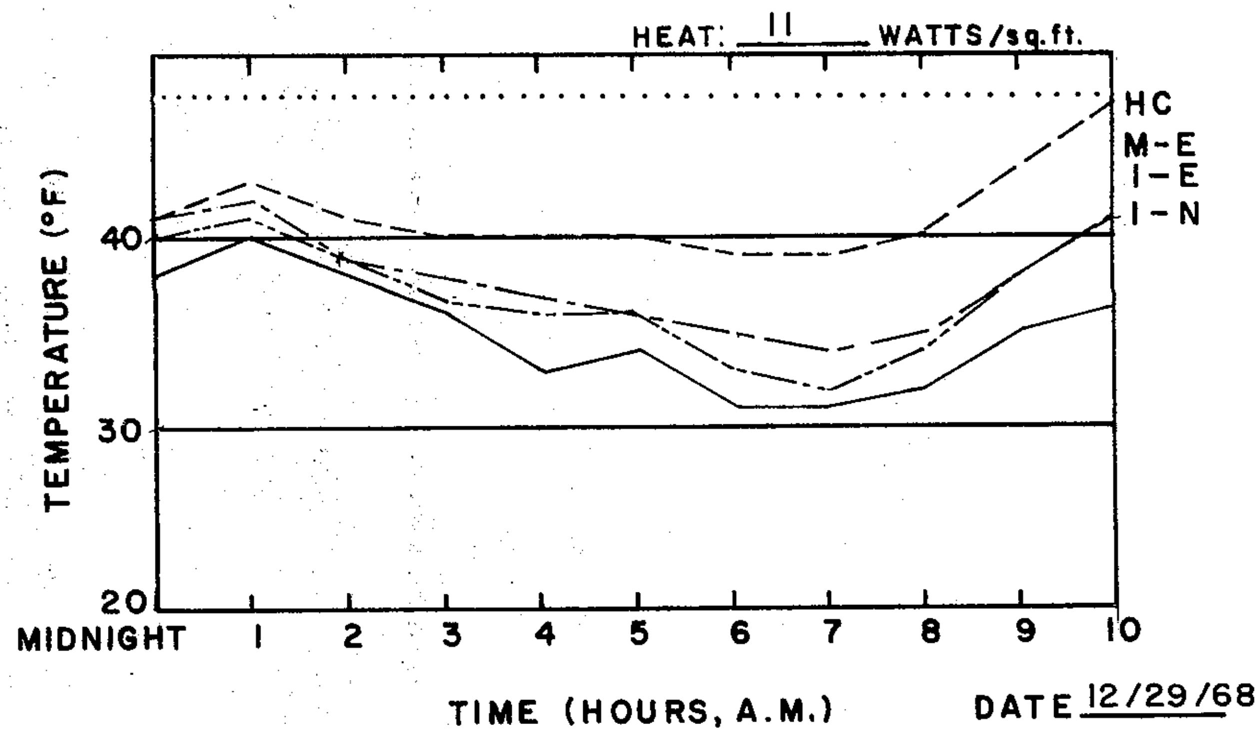



# TEMPERATURE AND ICE DETECTION

## MERCED RIVER BRIDGE

| LEGEND | | EVENTS ON | |
|---|---|---|---|
| ——————— | AIR TEMPERATURE | HC = HEATING CABLES | . . . . . |
| — — — — — | HEATED CELL DECK TEMP | M—E = MOISTURE - ECONOLITE | o o o |
| ——— — ——— | INSULATED CELL DECK TEMP | I - E = ICE - ECONOLITE | + + + + |
| ——— - - ——— | UNINSULATED CELL DECK TEMP | I - N = ICE - NELSON | x x x x |

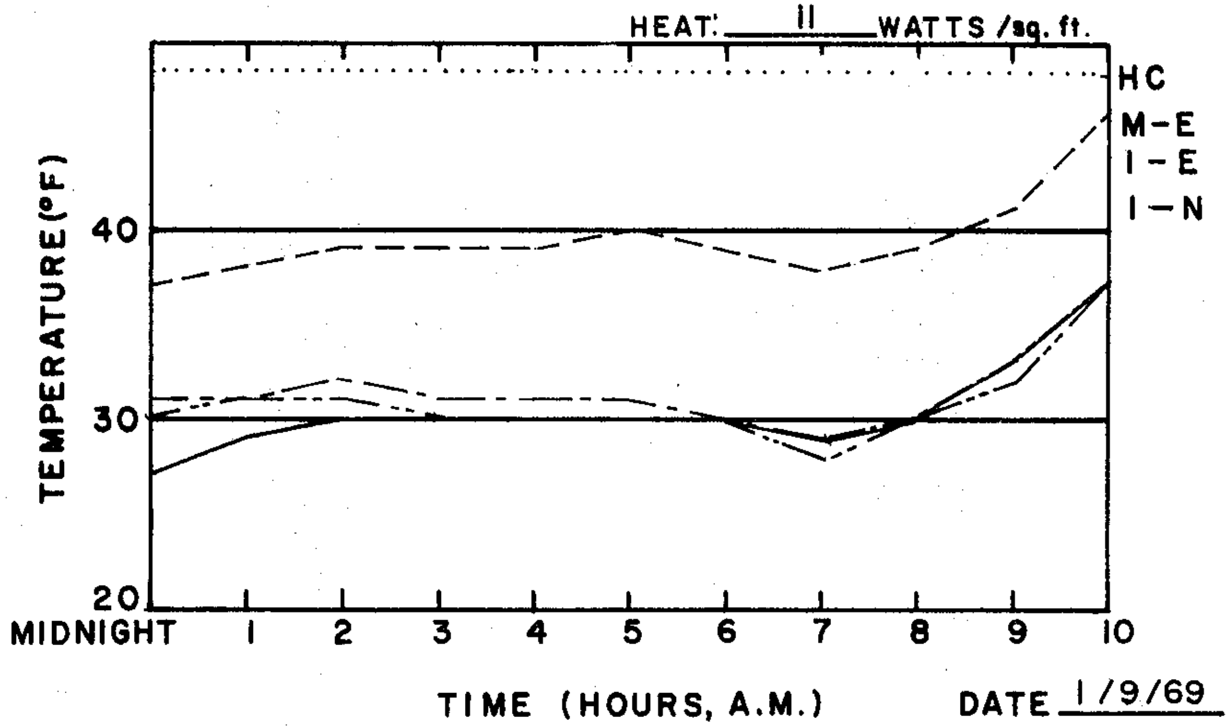


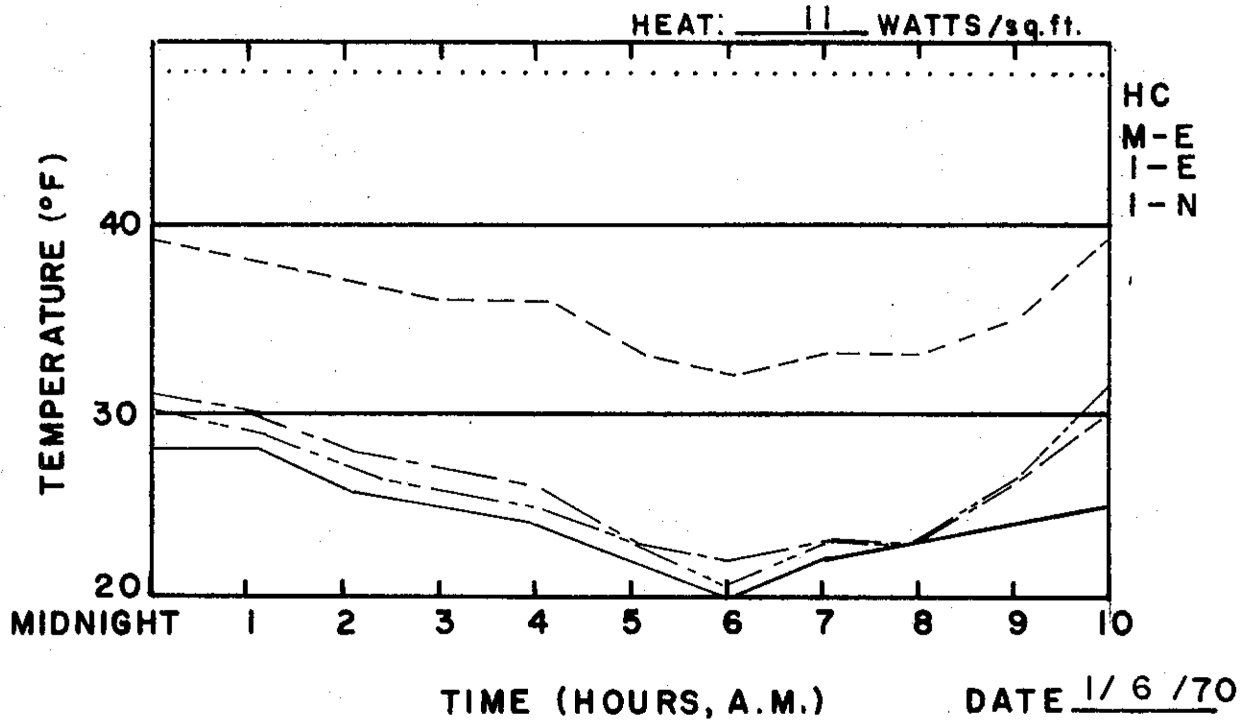



# TEMPERATURE AND ICE DETECTION

## MERCED RIVER BRIDGE

| LEGEND | | EVENTS ON | |
|---|---|---|---|
| ———— | AIR TEMPERATURE | HC = HEATING CABLES | ........ |
| — — — — | HEATED CELL DECK TEMP | M—E = MOISTURE - ECONOLITE | o o o |
| ——- —— | INSULATED CELL DECK TEMP | I - E = ICE - ECONOLITE | + + + + |
| ——- - -—— | UNINSULATED CELL DECK TEMP | I - N = ICE - NELSON | x x x x |

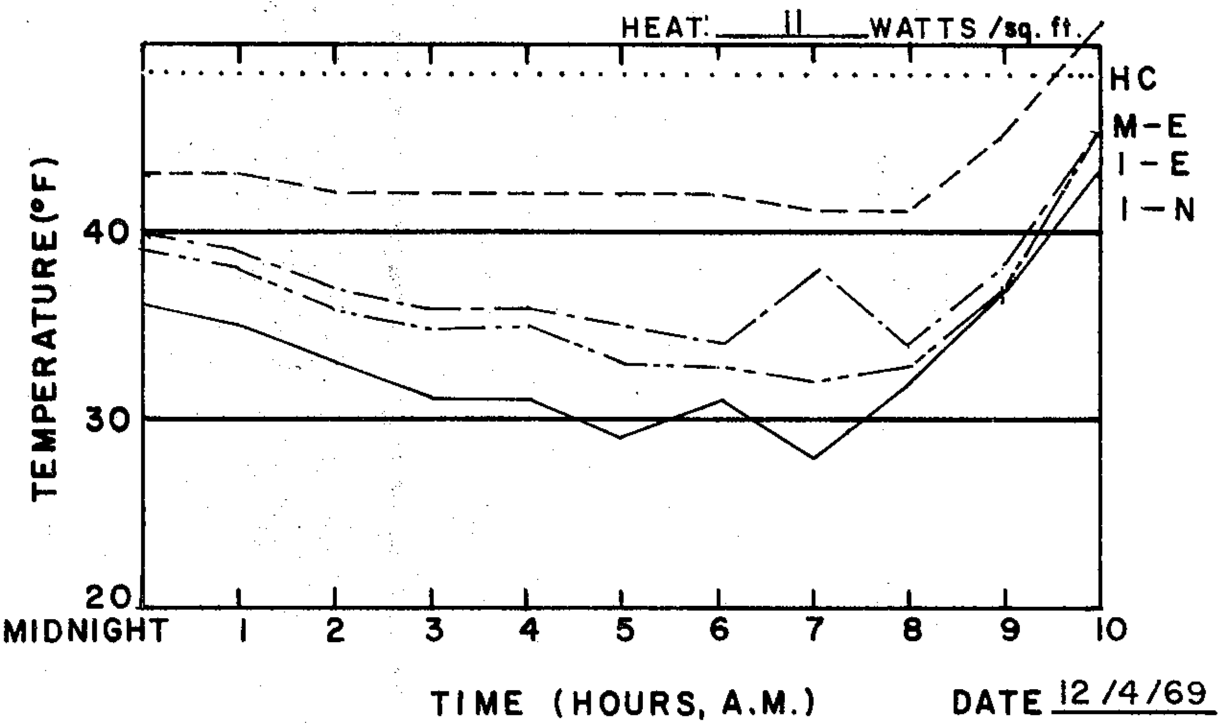


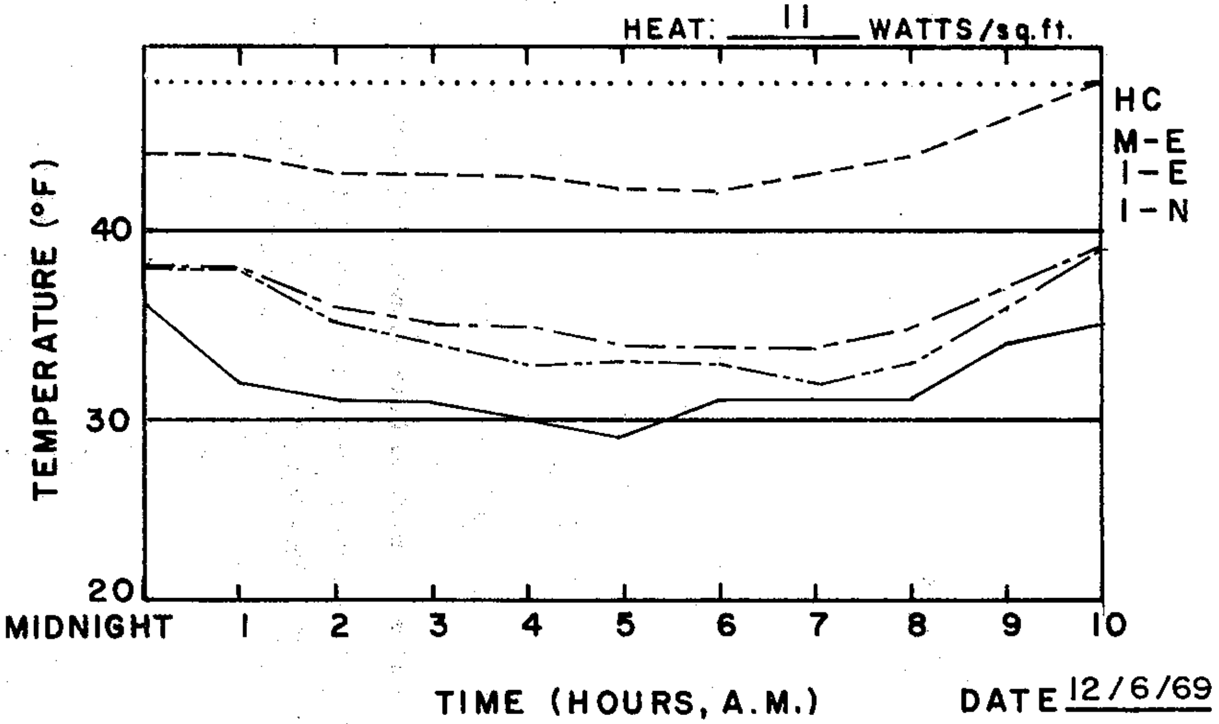



# TEMPERATURE AND ICE DETECTION

## MERCED RIVER BRIDGE

| LEGEND | | EVENTS ON | |
|---|---|---|---|
| ——— | AIR TEMPERATURE | HC = HEATING CABLES | ..... |
| – – – – | HEATED CELL DECK TEMP | M–E = MOISTURE - ECONOLITE | o o o |
| —-—- | INSULATED CELL DECK TEMP | I – E = ICE - ECONOLITE | + + + + |
| —-·-·— | UNINSULATED CELL DECK TEMP | I – N = ICE - NELSON | x x x x |

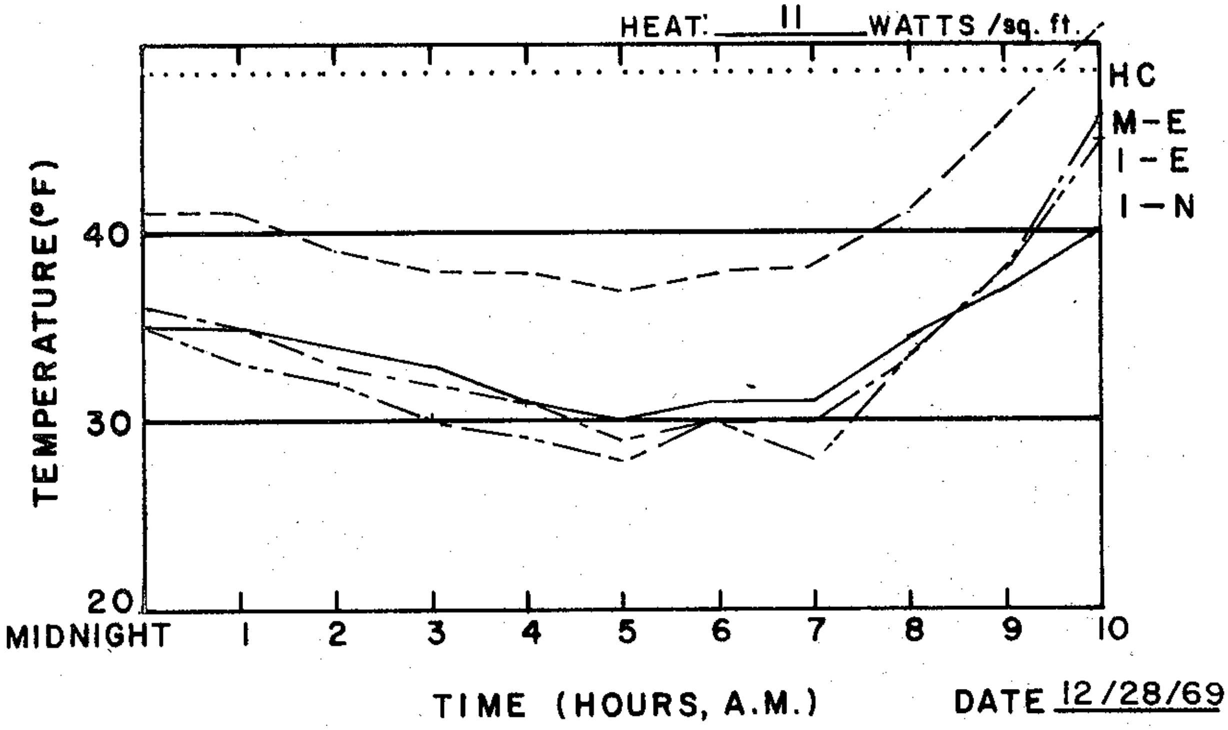


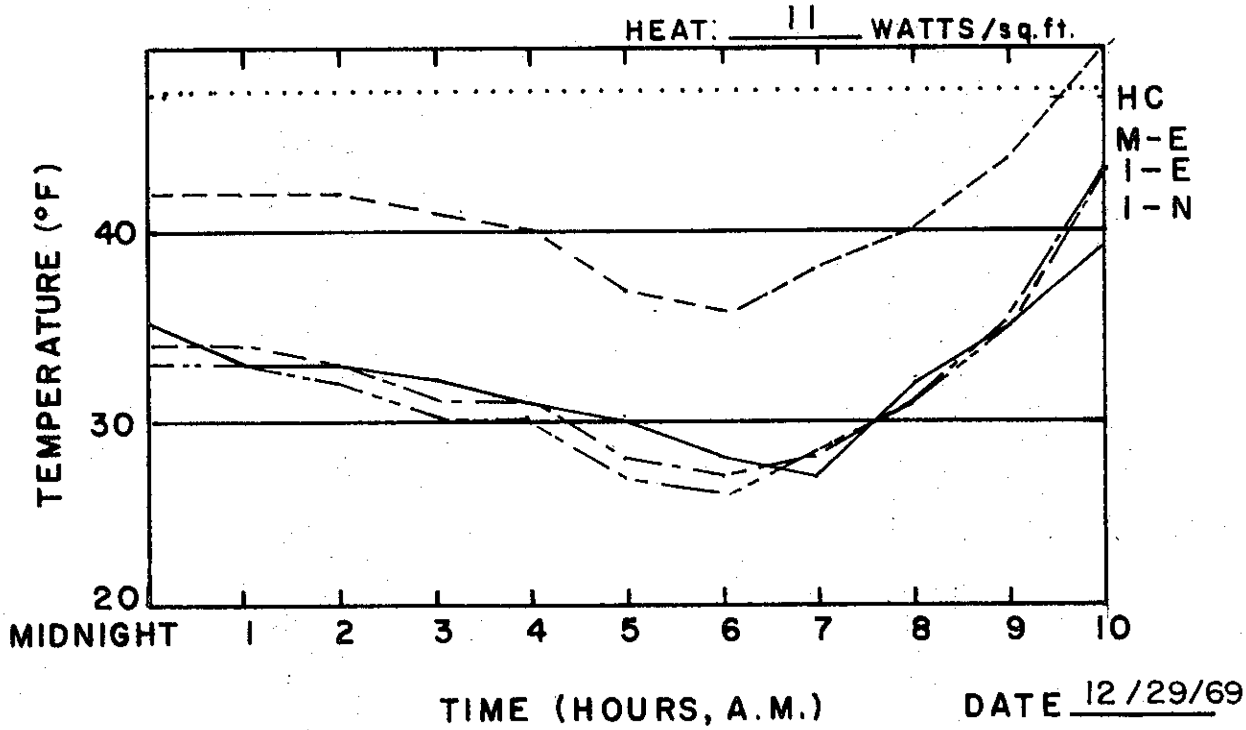



# TEMPERATURE AND ICE DETECTION

## MERCED RIVER BRIDGE

| LEGEND | EVENTS ON |
|---|---|
| ———— AIR TEMPERATURE | HC = HEATING CABLES ······ |
| – – – – – HEATED CELL DECK TEMP | M – E = MOISTURE – ECONOLITE o o o |
| ——-—— INSULATED CELL DECK TEMP | I – E = ICE – ECONOLITE + + + + + |
| ——-·-—— UNINSULATED CELL DECK TEMP | I – N = ICE – NELSON x x x x |

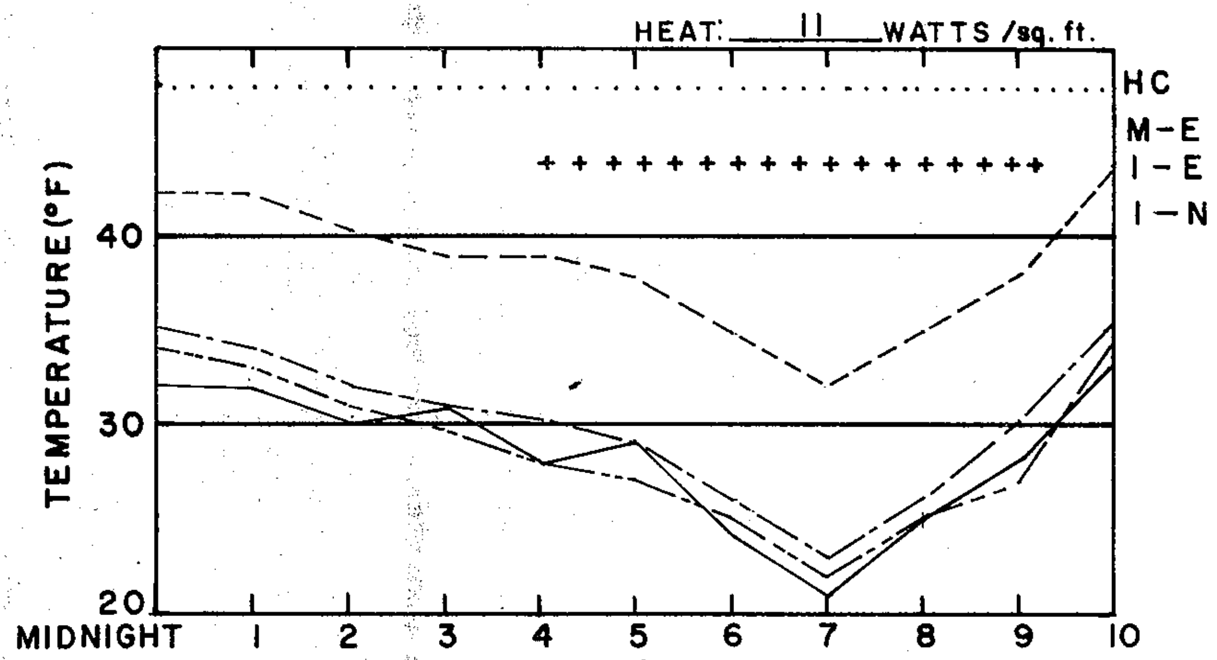


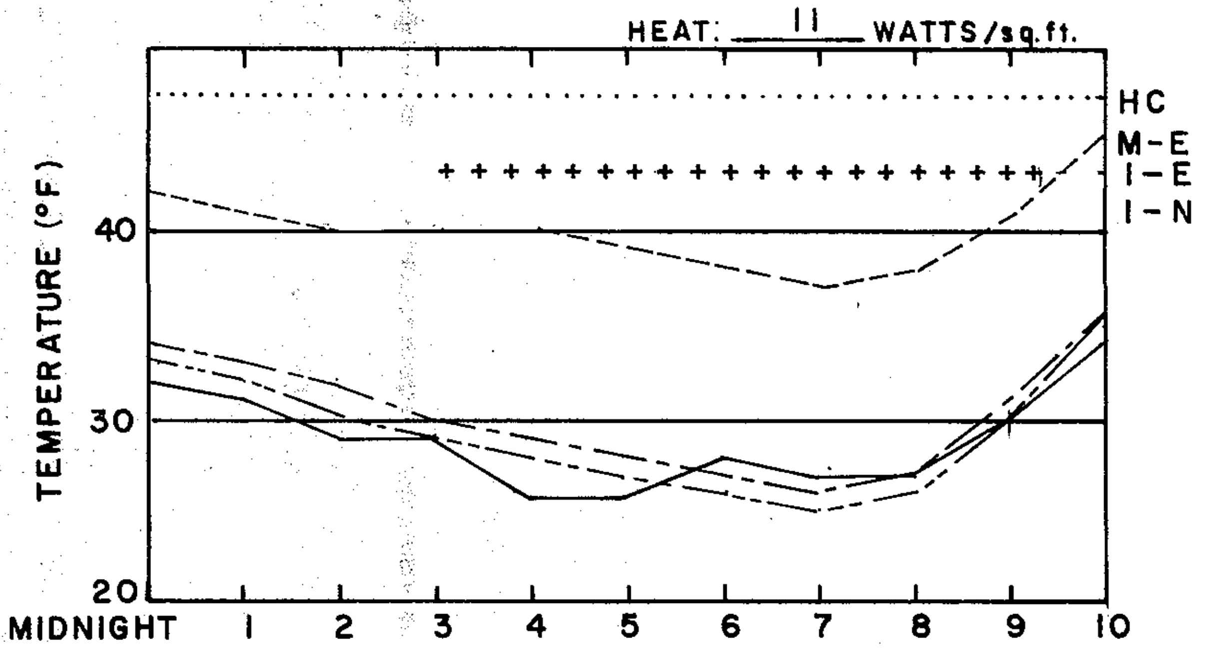
# TEMPERATURE AND ICE DETECTION

## MERCED RIVER BRIDGE

| LEGEND | EVENTS ON |
|---|---|
| ——— AIR TEMPERATURE | HC = HEATING CABLES ······ |
| – – – – — HEATED CELL DECK TEMP | M–E = MOISTURE – ECONOLITE ooo |
| ——– - ——— INSULATED CELL DECK TEMP | I – E = ICE – ECONOLITE ++++ |
| ———- - - ——— UNINSULATED CELL DECK TEMP | I – N = ICE – NELSON xxxx |




TIME (HOURS, A.M.) DATE 12/31/69

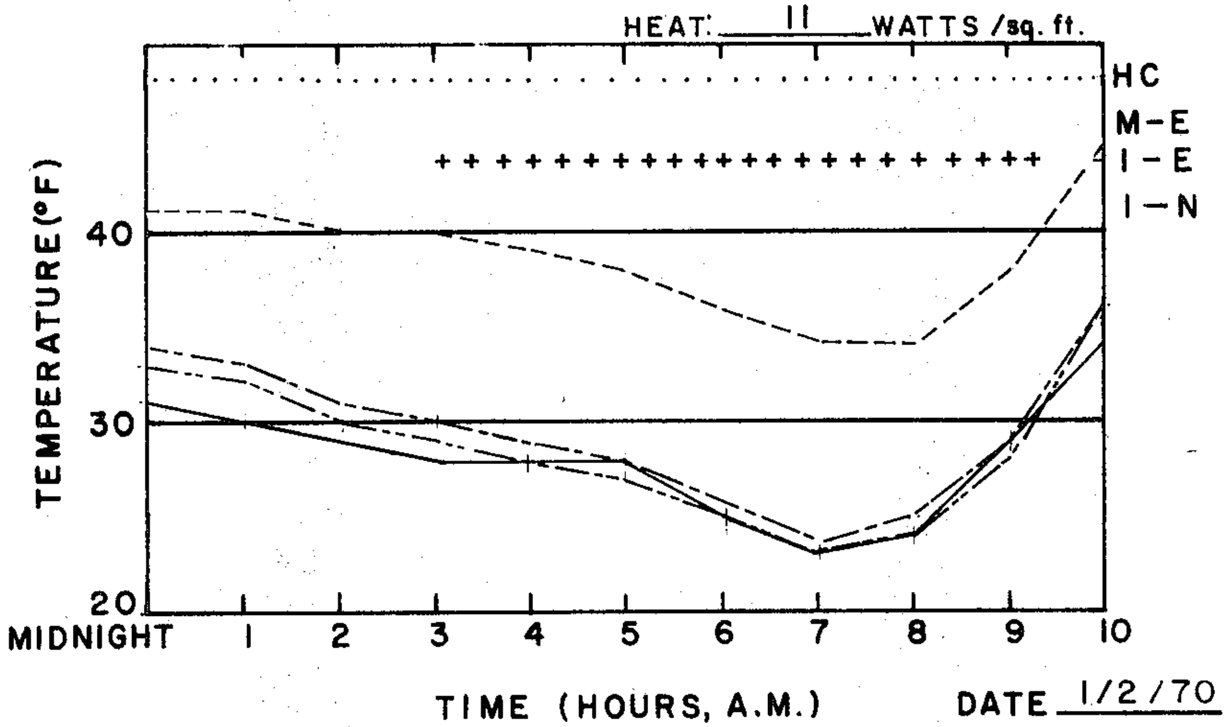


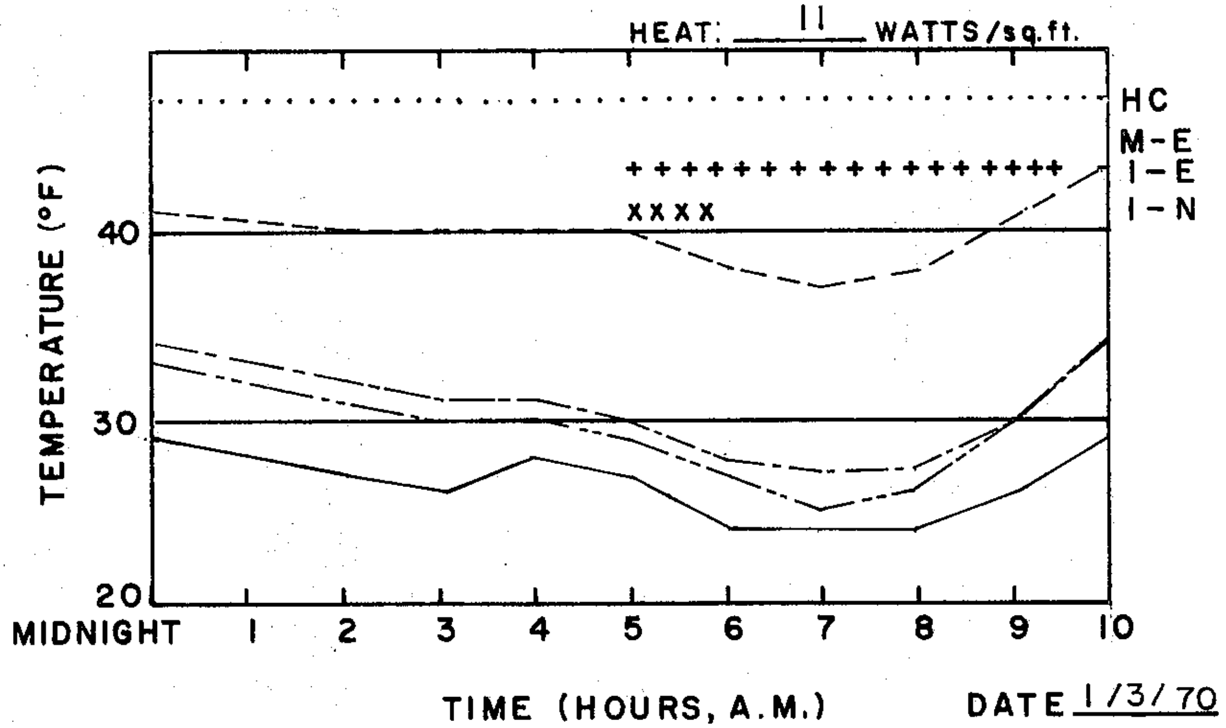

TIME (HOURS, A.M.) DATE 1/1/70

# TEMPERATURE AND ICE DETECTION

## MERCED RIVER BRIDGE

| LEGEND | EVENTS ON |
|---|---|
| ——— AIR TEMPERATURE | HC = HEATING CABLES ...... |
| – – – – – HEATED CELL DECK TEMP | M–E = MOISTURE - ECONOLITE ooo |
| ——-—— INSULATED CELL DECK TEMP | I – E = ICE - ECONOLITE ++++ |
| ——-·-—— UNINSULATED CELL DECK TEMP | I – N = ICE - NELSON xxxx |

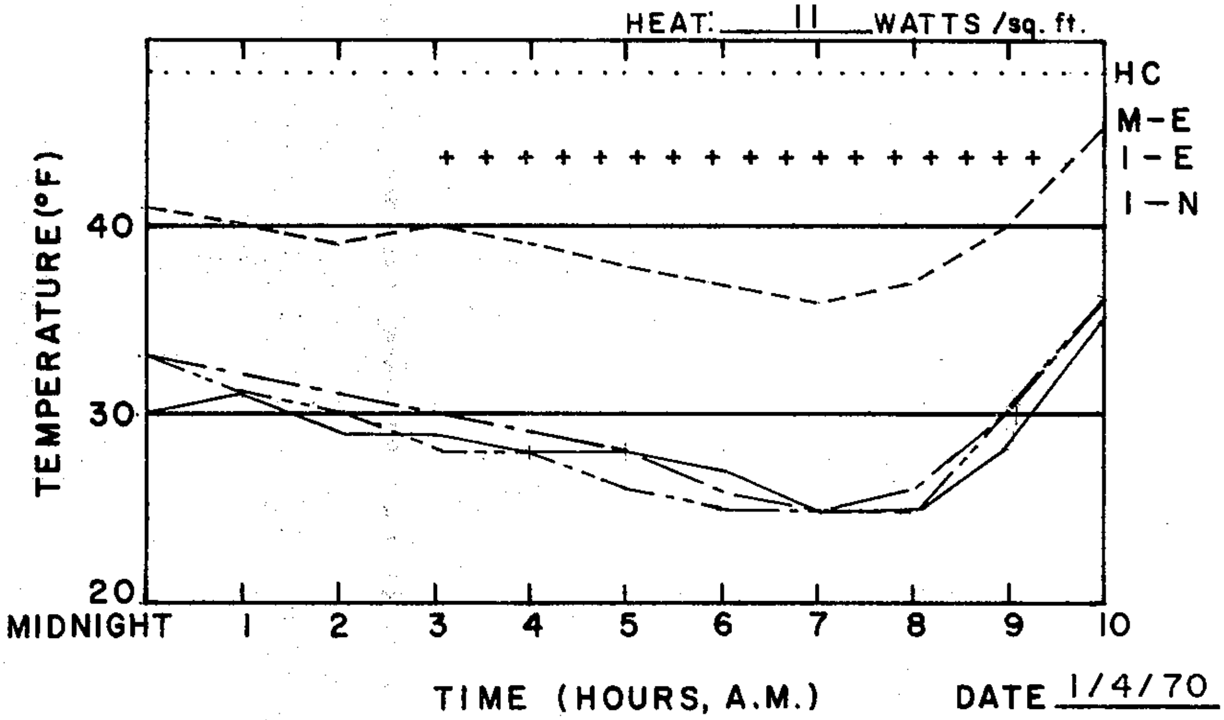


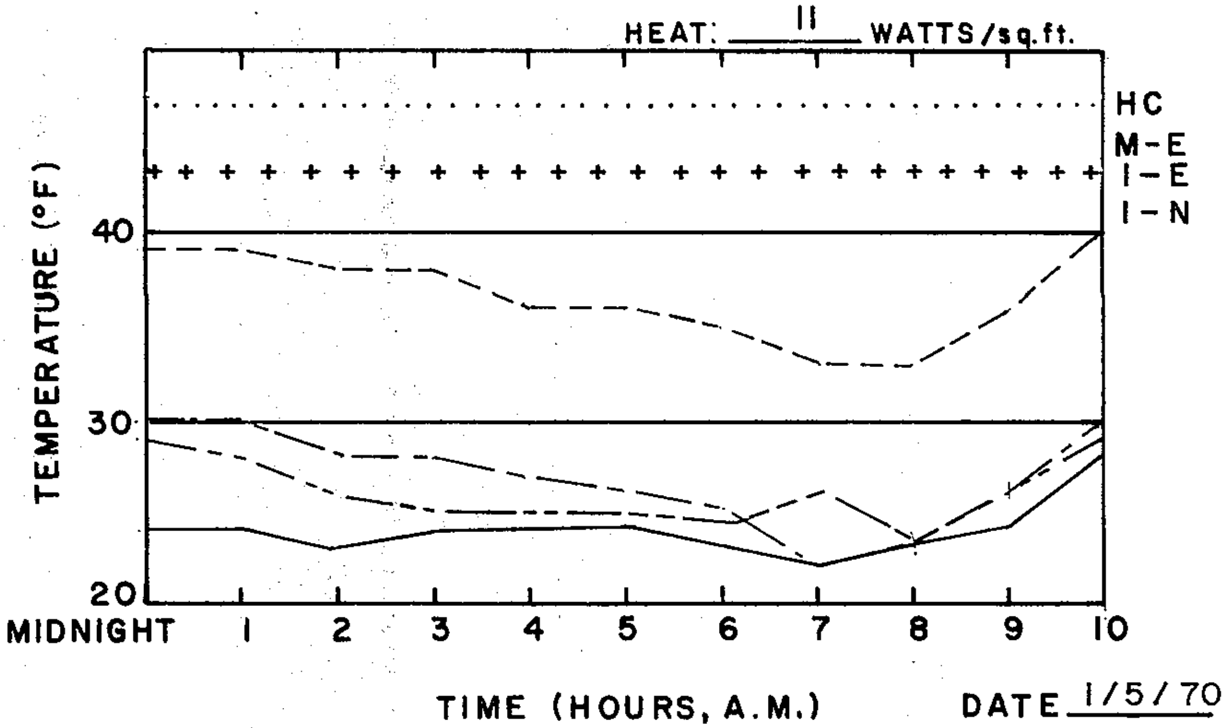



# TEMPERATURE AND ICE DETECTION

## MERCED RIVER BRIDGE

| LEGEND | | EVENTS ON | |
|---|---|---|---|
| ———— | AIR TEMPERATURE | HC = HEATING CABLES | ····· |
| — — — — | HEATED CELL DECK TEMP | M—E = MOISTURE - ECONOLITE | o o o |
| —— - —— | INSULATED CELL DECK TEMP | I - E = ICE - ECONOLITE | ++++ |
| —— - · —— | UNINSULATED CELL DECK TEMP | I - N = ICE - NELSON | x x x x |



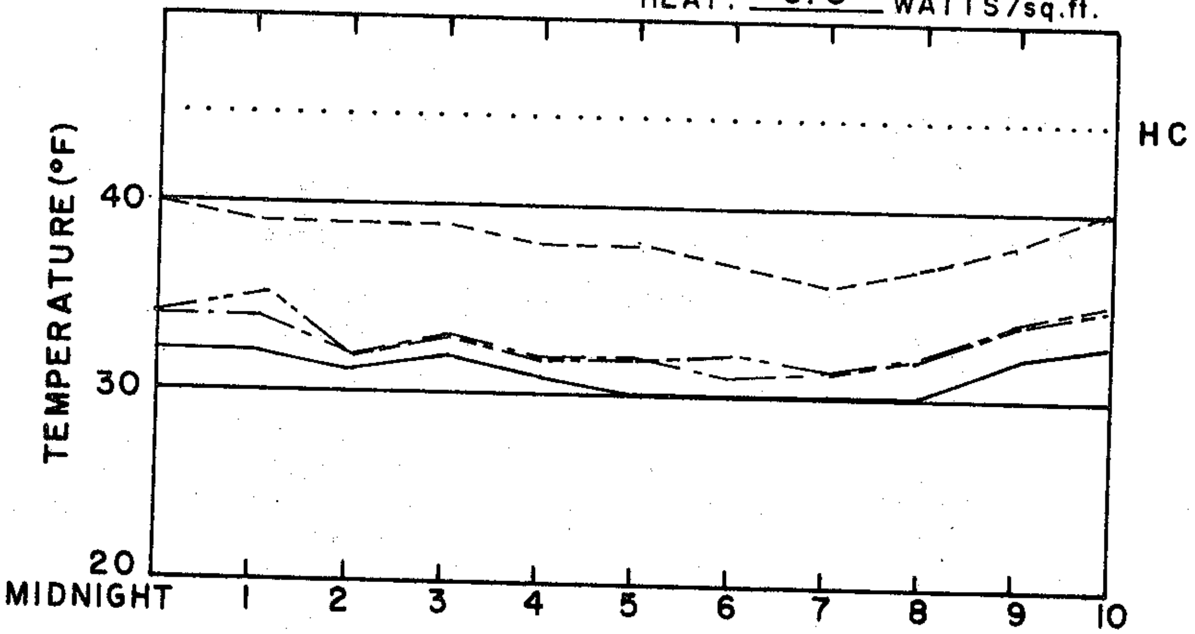
# TEMPERATURE AND ICE DETECTION
## WEBSTER STREET BRIDGE

LEGEND

———— AIR TEMPERATURE
— — — — HEATED CELL DECK TEMP
—— – – —— INSULATED CELL DECK TEMP
—— – – – – UNINSULATED CELL DECK TEMP

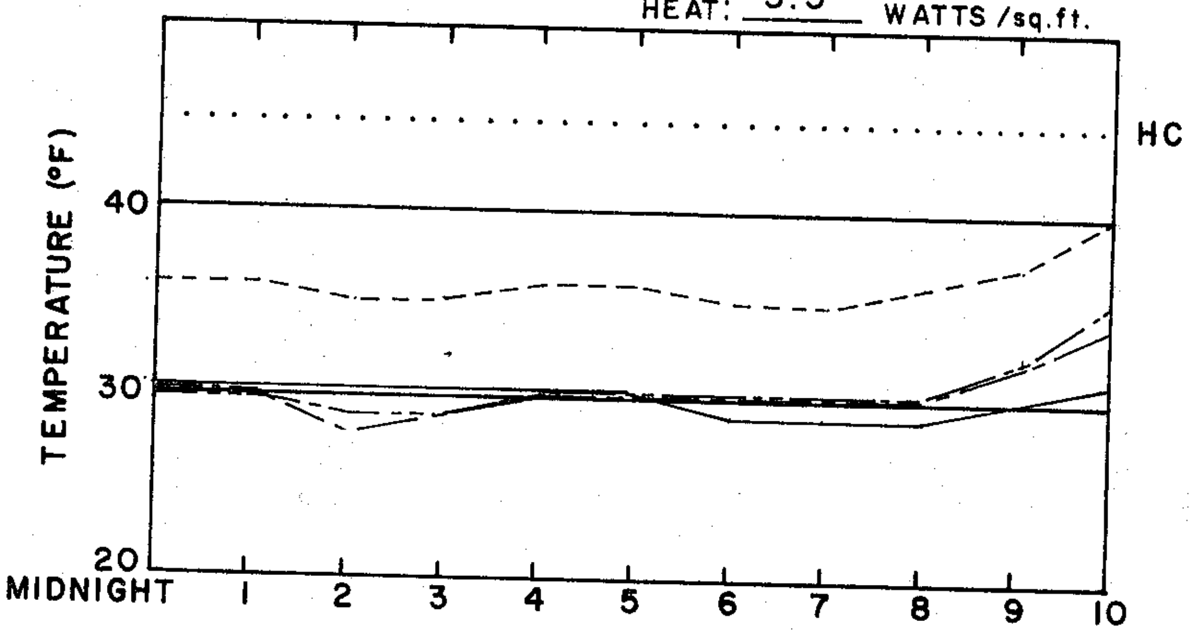
EVENTS ON
HC= HEATING CABLES .....

HEAT: 3.5 WATTS/sq.ft.




TIME (HOURS, A.M.) DATE 1/9/69

HEAT: 3.5 WATTS/sq.ft.




TIME (HOURS, A,M.) DATE 1/10/69

# TEMPERATURE AND ICE DETECTION

## WEBSTER STREET BRIDGE

LEGEND

—————— AIR TEMPERATURE

— — — — — HEATED CELL DECK TEMP

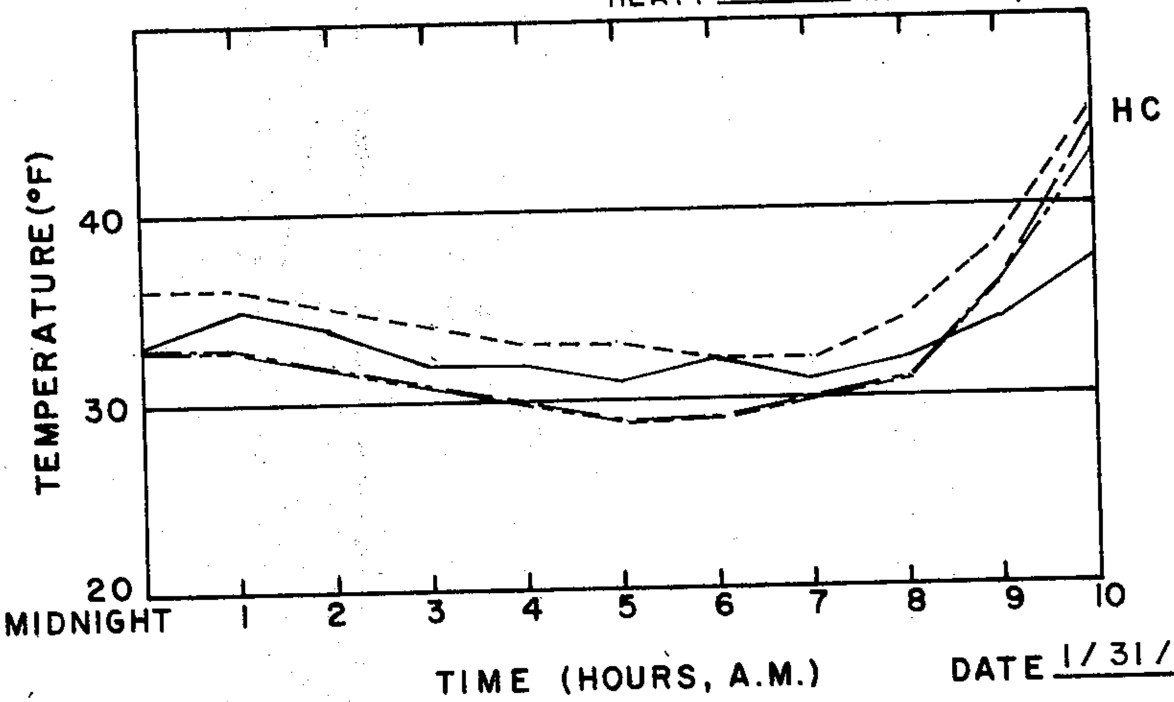
——— — — ——— INSULATED CELL DECK TEMP

——— — — — ——— UNINSULATED CELL DECK TEMP

EVENTS ON

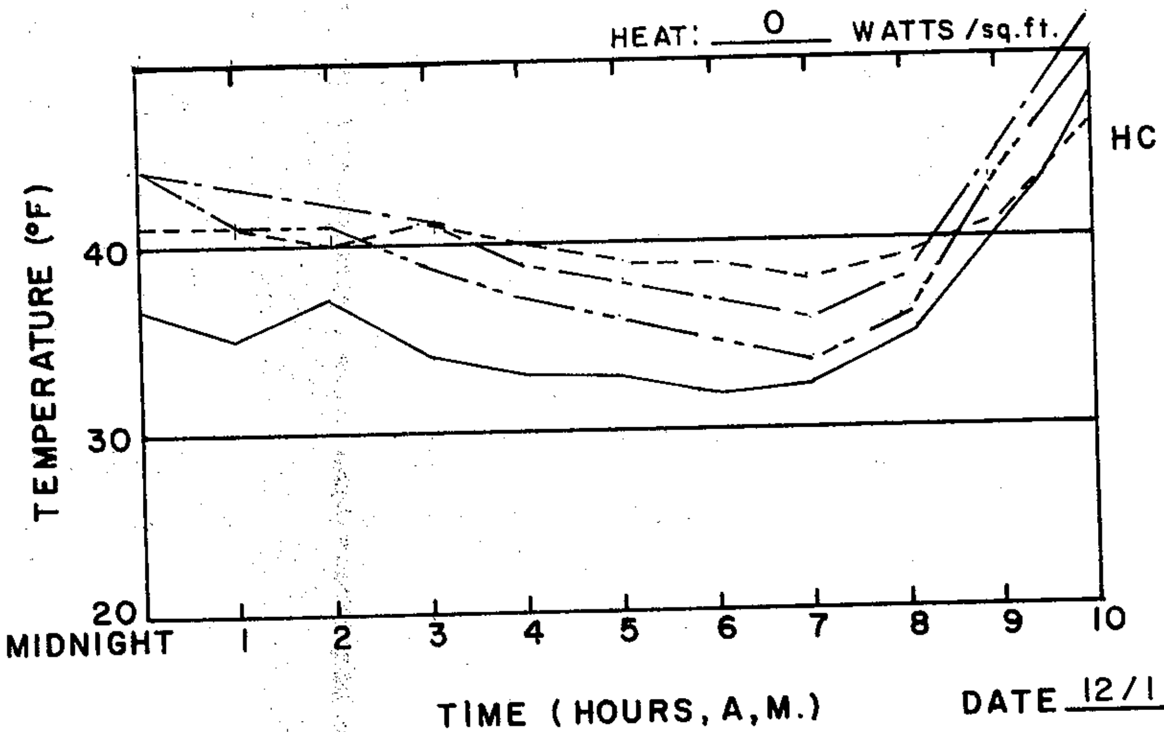
HC= HEATING CABLES .....

HEAT: 0 WATTS/sq.ft.




DATE 1/31/69

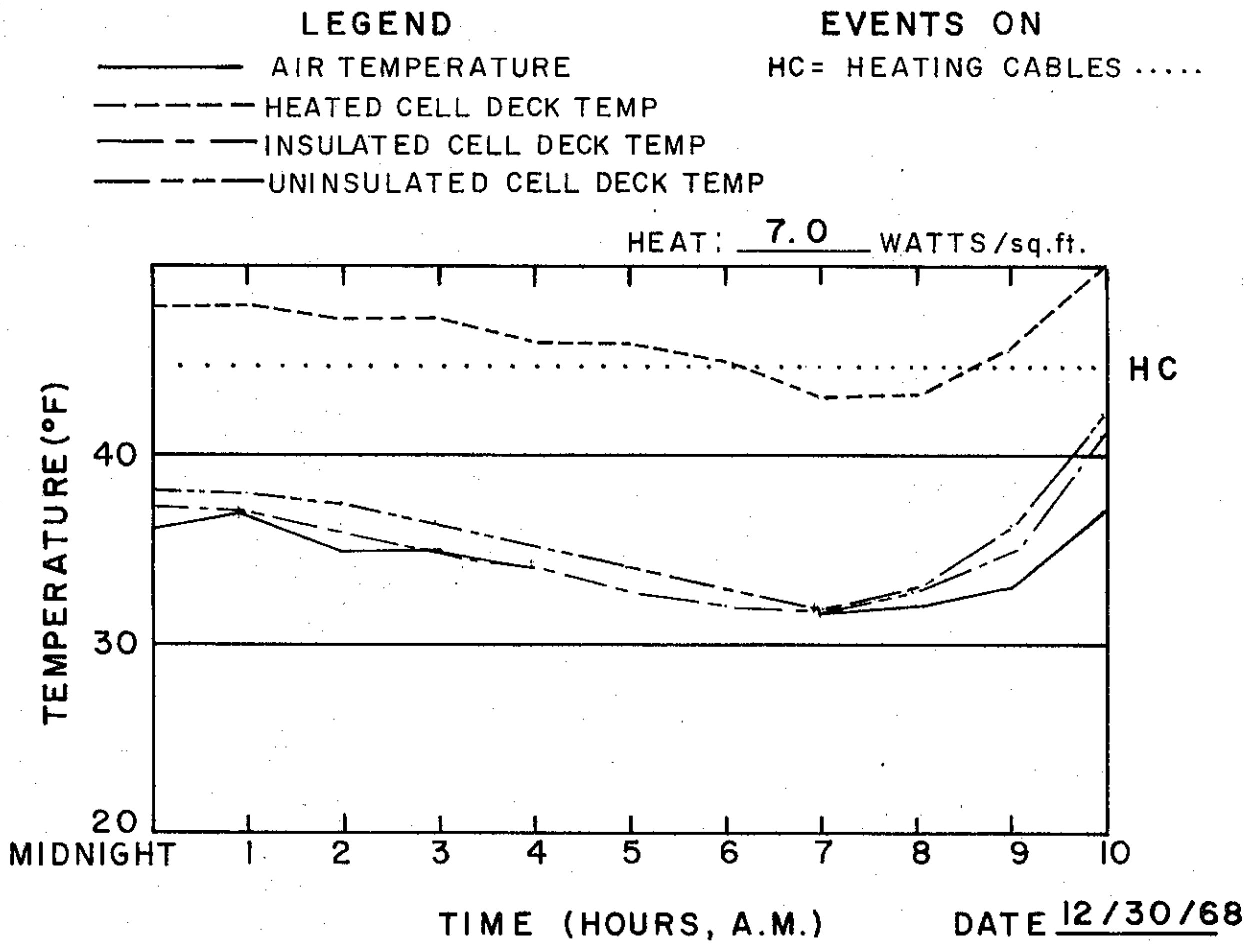
HEAT: 0 WATTS/sq.ft.




DATE 12/1/69

# TEMPERATURE AND ICE DETECTION

## WEBSTER STREET BRIDGE

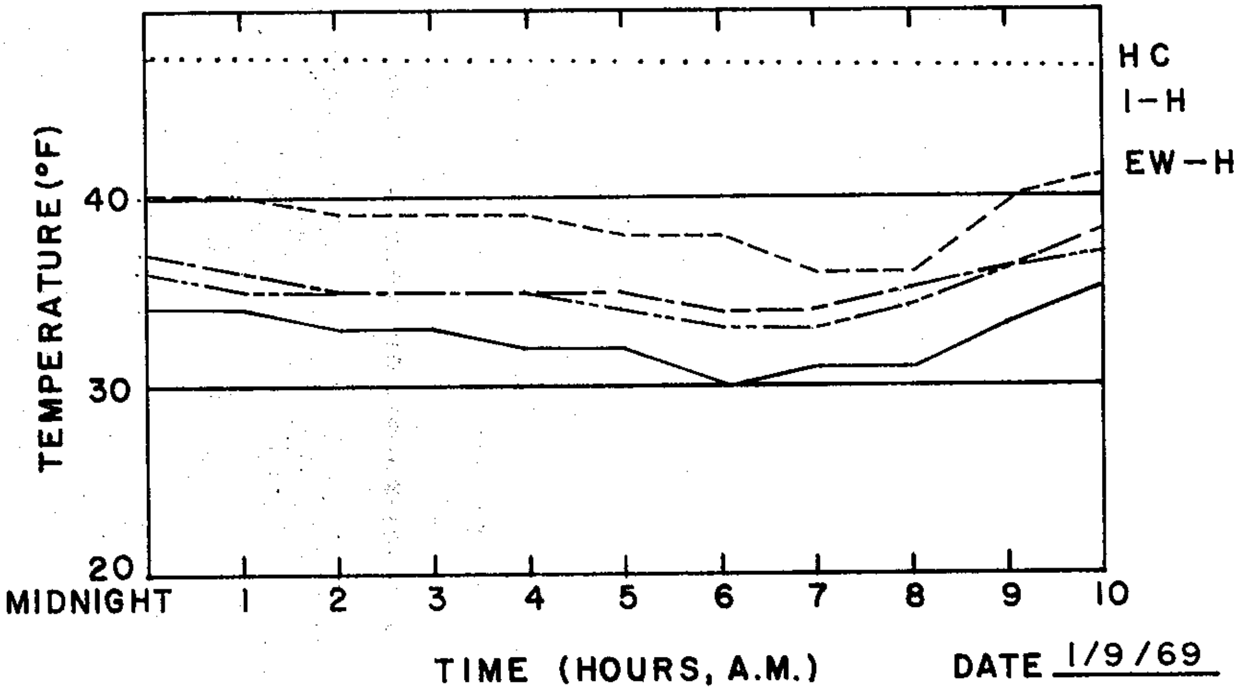


# TEMPERATURE AND ICE DETECTION

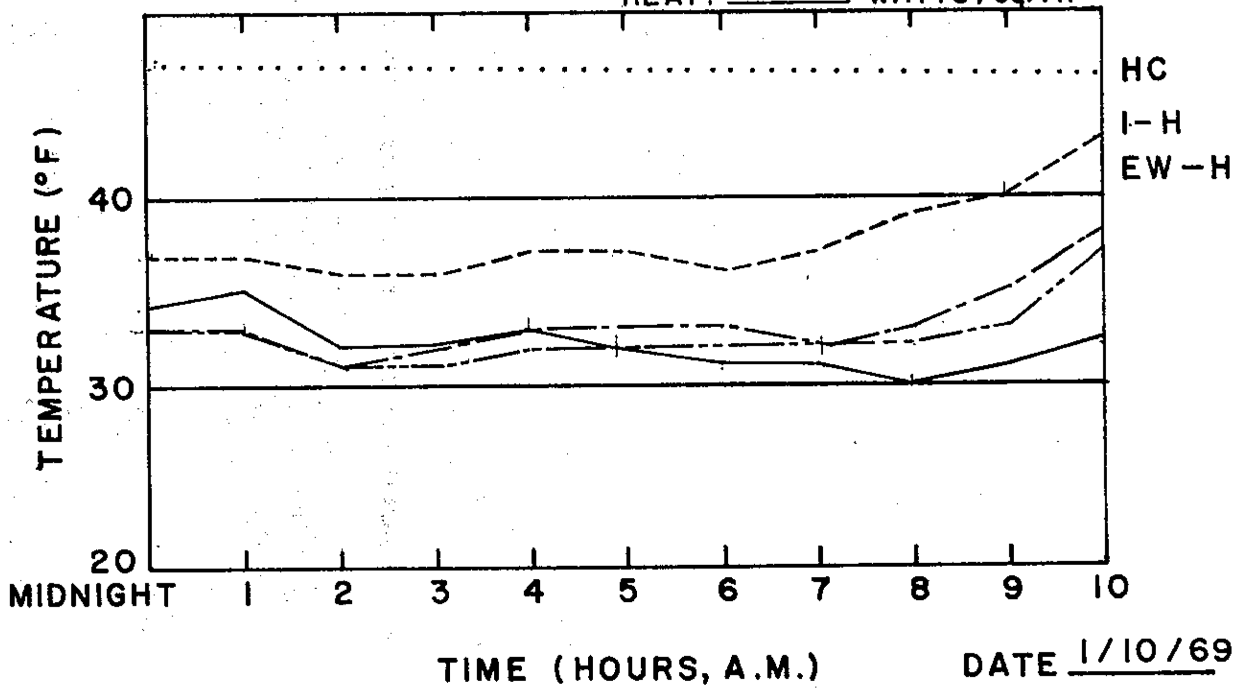
## YOLO CAUSEWAY

| LEGEND | | EVENTS ON | |
|---|---|---|---|
| ———— | AIR TEMPERATURE | HC = HEATING CABLES | ....... |
| – – – – – | HEATED CELL DECK TEMP | I–H = ICE HOLLEY | + + + + |
| —— —— | INSULATED CELL DECK TEMP | EW–H = EARLY WARNING — HOLLEY | x x x x |
| —·—·— | UNINSULATED CELL DECK TEMP | | |

HEAT: 5 WATTS/sq.ft.



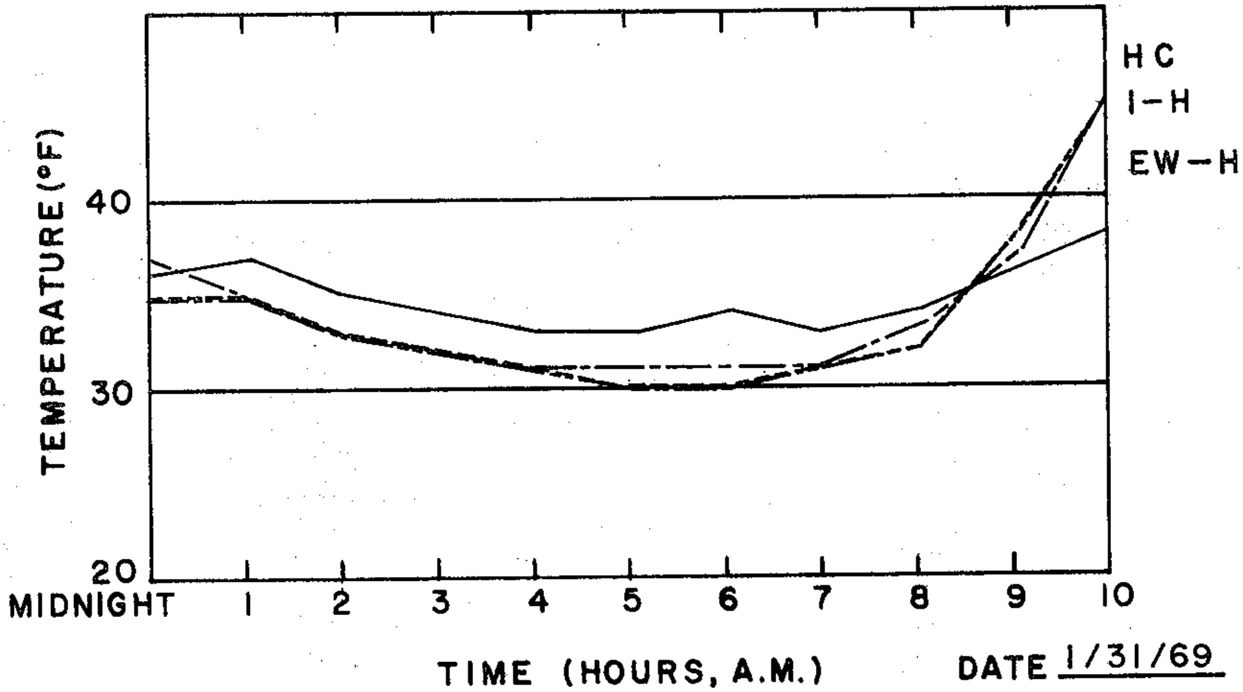

HEAT: 5 WATTS/sq.ft.



# TEMPERATURE AND ICE DETECTION
## YOLO CAUSEWAY

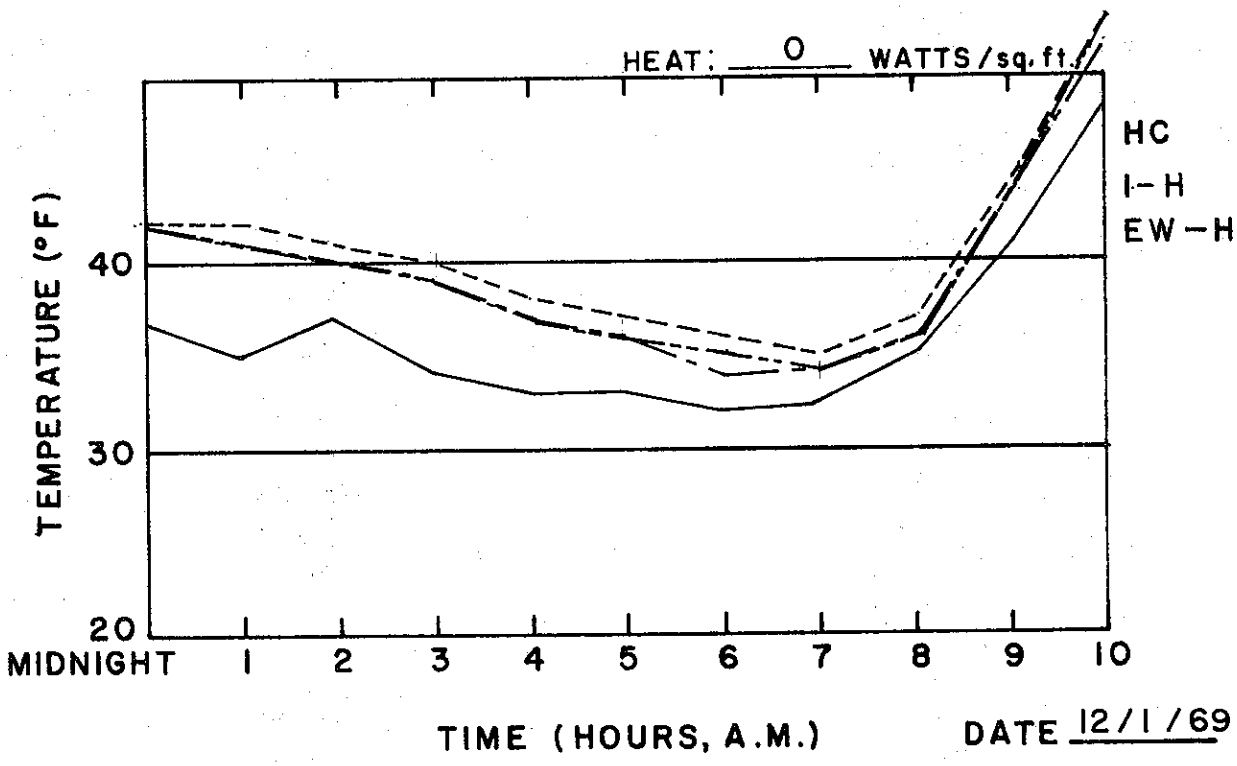
| LEGEND | EVENTS ON |
|---|---|
| ——— AIR TEMPERATURE | HC= HEATING CABLES . . . . . |
| – – – – – HEATED CELL DECK TEMP | I-H = ICE HOLLEY + + + + |
| —— — —— INSULATED CELL DECK TEMP | EW-H = EARLY WARNING— HOLLEY x x x x |
| ——-—-—— UNINSULATED CELL DECK TEMP | |

HEAT: 0 WATTS/sq.ft.




DATE 1/31/69

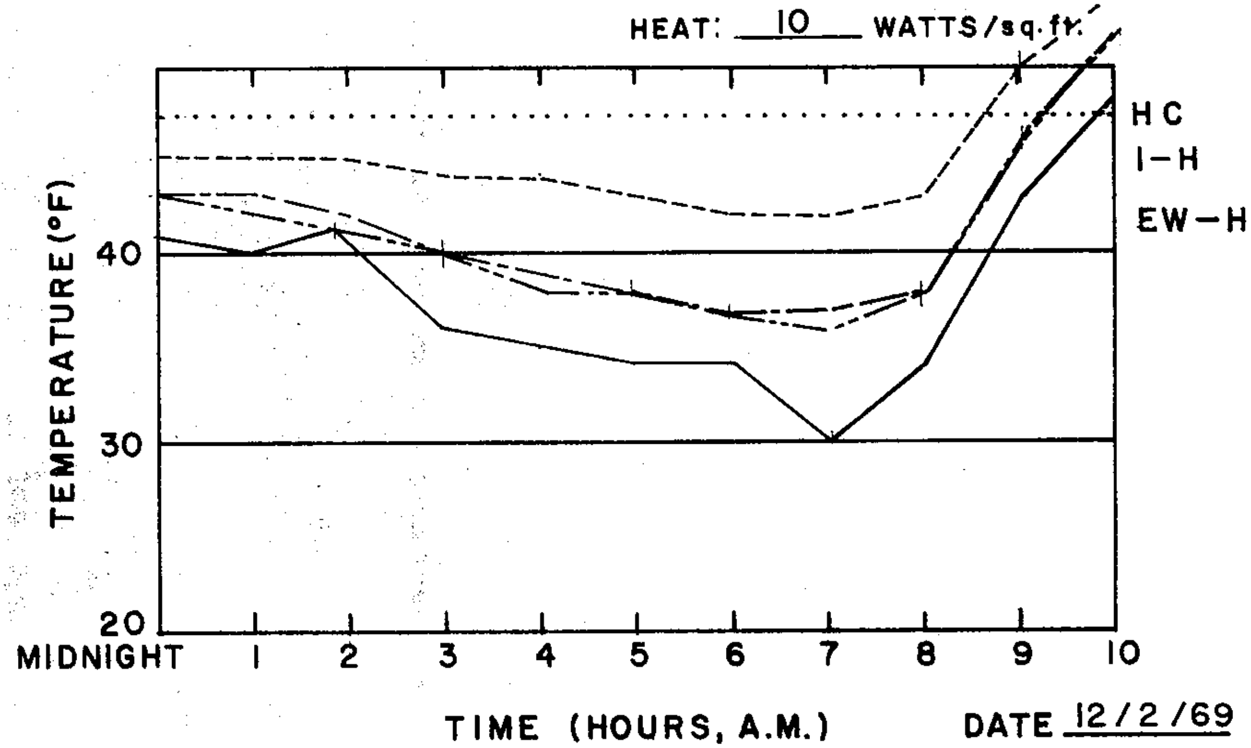
HEAT: 0 WATTS/sq.ft.

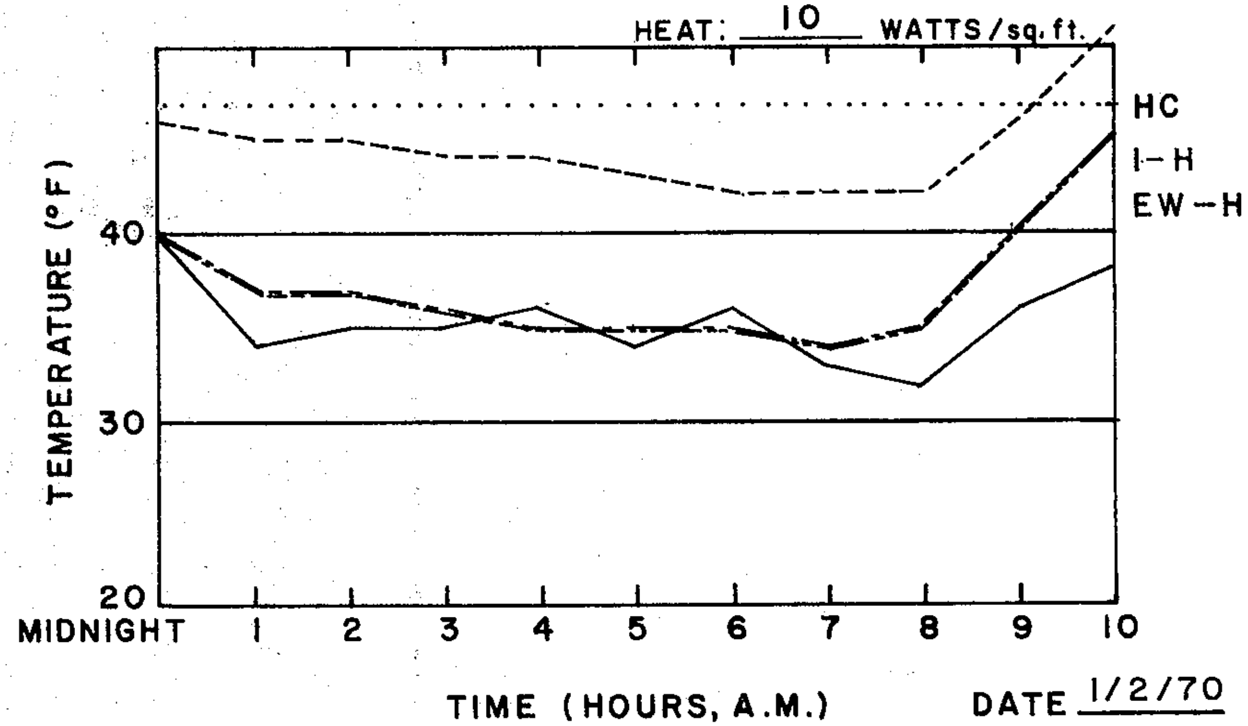



DATE 12/1/69

# TEMPERATURE AND ICE DETECTION
## YOLO CAUSEWAY

| LEGEND | | EVENTS ON | |
|---|---|---|---|
| ———— | AIR TEMPERATURE | HC = HEATING CABLES | ······ |
| – – – – – | HEATED CELL DECK TEMP | I-H = ICE HOLLEY | + + + + |
| —— – —— | INSULATED CELL DECK TEMP | EW-H = EARLY WARNING— HOLLEY | x x x x |
| ——·–·–· | UNINSULATED CELL DECK TEMP | | |



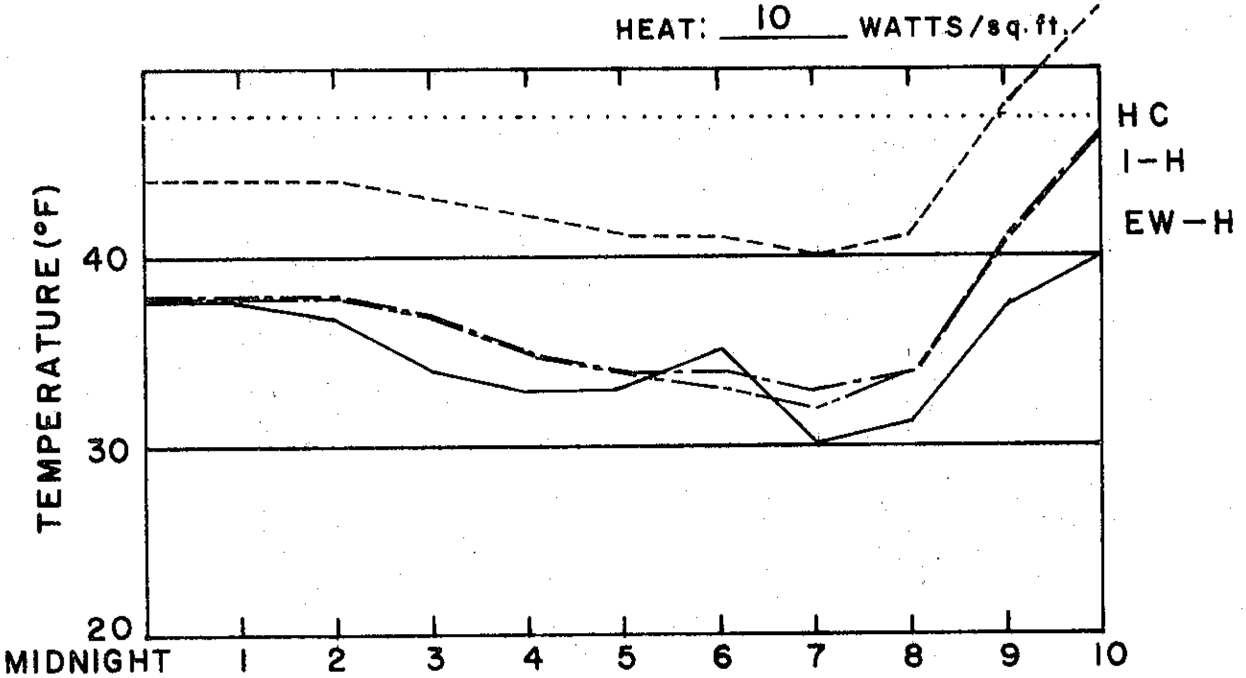



# TEMPERATURE AND ICE DETECTION

## YOLO CAUSEWAY

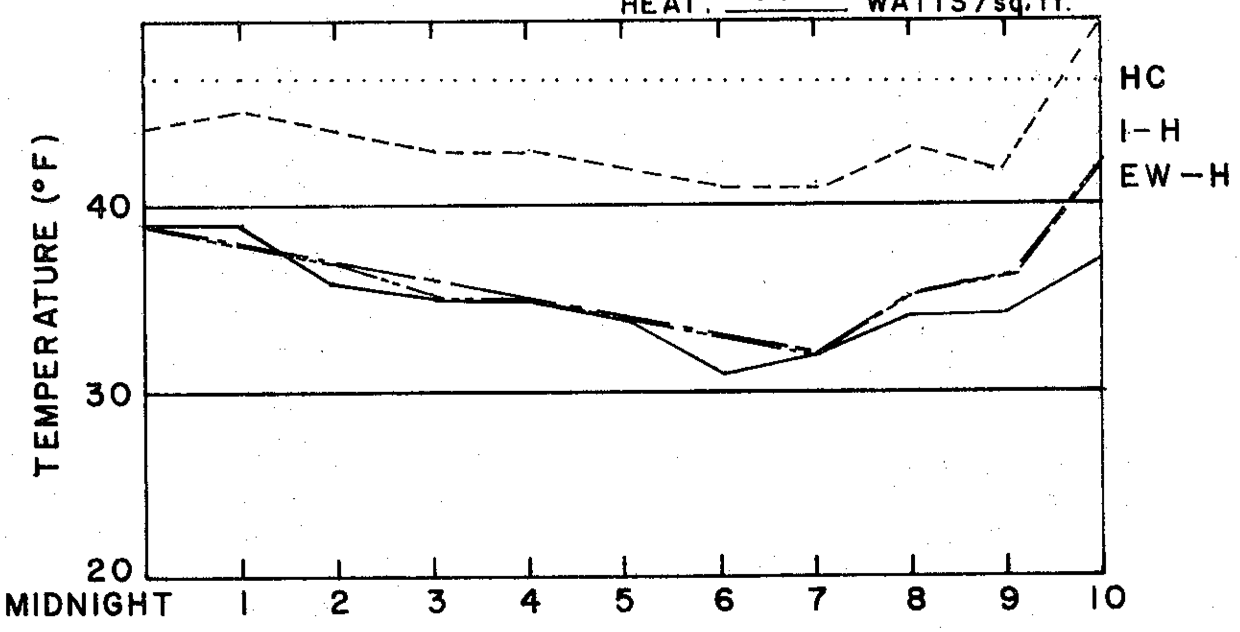
| LEGEND | EVENTS ON |
|---|---|
| ———— AIR TEMPERATURE | HC = HEATING CABLES ....... |
| – – – – – HEATED CELL DECK TEMP | I-H = ICE HOLLEY ++++ |
| —— —— INSULATED CELL DECK TEMP | EW-H = EARLY WARNING — HOLLEY xxxx |
| —·—·— UNINSULATED CELL DECK TEMP | |

HEAT: 10 WATTS/sq.ft.




TIME (HOURS, A.M.) DATE 1/3/70

HEAT: 10 WATTS/sq.ft.




TIME (HOURS, A.M.) DATE 1/4/70

# TEMPERATURE AND ICE DETECTION

## YOLO CAUSEWAY